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The impact of climate change on human health: some international implications

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Abstract. The objective of this study is to discuss the potential impact of a global warming on various aspects of human health. Changes in heat-related mortality are estimated for four countries: the United States, Canada, the People's Republic of China and Egypt. In addition, the potential confounding impact of increased air pollution is considered. Finally, a framework to analyze two vector-borne diseases, onchocerciasis and malaria, which may spread if temperatures increase, is discussed. Our findings suggest that heat-related mortality is estimated to rise significantly in all four countries if the earth warms, with the greatest impacts in China and Egypt. The most sensitive areas are those with intense but irregular heat waves. In the United States, air pollution does not appear to impact daily mortality significantly when severe weather is present, although it seems to have a slight influence when weather conditions are not stressful.
Key words. Climate change; mortality; heat stress; vector-borne disease.

Introduction

There has been a growing concern in both the medical and climatological communities that a significant global warming could create major international health problems. Research recently completed and described in several papers indicates that a global warming could have a major impact on the number of heat-related deaths in the United States[15,17,24]. Considering that most people in the United States have some access to air conditioning – which might mitigate the impact of global warming on human health – the impact of heat-related mortality in many other regions might be more extreme. This is especially true in developing countries, where the general population is more exposed to the vagaries of the weather. Although a global warming could increase heat-related mortality, these effects could possibly be mitigated by a decrease in winter weather-related mortality. The impacts of winter weather on mortality are less obvious than those of summer weather and are poorly understood.

The confounding influence of air pollution on acute human mortality represents another area of uncertainty surrounding climate/human health relationships. There have been conflicting results regarding the impact of pollution on mortality in the United States. For example, Schwartz and Dockery[23], have determined that human health in Los Angeles and other areas is markedly impacted by variations in air pollution concentration. However, our work indicates that daily mortality fluctuations are much more sensitive to weather than to pollution concentration in 10 U.S. cities[14].

Another major health impact of a long-term climatic change involves the spread of debilitating infectious diseases, whose vectors might migrate poleward if the climate warms. It is not surprising, then, that the World Meteorological Organization (WMO) considers the international health ramifications of a global warming to be among the most pressing problems in the upcoming century[28]. The World Health Organization (WHO) expresses similar concern[27].

The goal of this paper is to summarize research on the potential impact of a global warming on human health. First, a discussion on potential changes in weather-related mortality will be presented for four countries: the United States, Canada, the People's Republic of China (PRC) and Egypt. Second, the potential confounding impact of increased air pollution will be considered. Third, a framework to analyze two vector-borne diseases which may spread in a warmer world will be discussed.

Literature review

Recent interest in climate/human health studies has dramatically increased, and at least four comprehensive reports summarizing most of this research have appeared in the last few years[7,19,26,27]. Two of these reports deal primarily with historical climate/health relationships, and shed little light on projected health problems under various global warming scenarios. However, Ewan et al.[7] devote much of their discussion to heat stress problems, infectious disease transmission, and potential mitigating strategies. The WHO report is divided into direct (heat-stress related illnesses) and indirect (transmission of infectious diseases) impacts[27]. Both documents provide ample evidence to suggest that human health may be severely impaired if the earth warms over the next century.

In the IPCC Working Group II Report[25], the potential impact of increased heat stress-induced mortality is recognized, but not expounded upon. Similar insufficient treatment is given to the problem of vector-borne infectious disease spread. Much of the IPCC health evaluation concentrates on UV-B exposure and related problems. A recent Electric Power Research Institute evaluation of the IPCC report[6] criticizes the IPCC for the perfunctory treatment afforded the potential major topics of heat stress-related mortality and spread of infectious diseases. In addition, the EPRI review points out that the IPCC neglected to evaluate regions where health might actually *improve* if a global warming takes place, such as those where winter weather conditions could become less severe.

A large majority of the research on global warming/health relationships has dealt with heat stress, with very little concentration on infectious disease problems. Kalkstein[10–12] has written specifically on domestic heat stress/mortality impacts of a global warming, and more generally on climate change and public health problems[12,13,15]. Haile[8] developed computer simulations evaluating potential patterns of vector-borne disease transmission in a warmer world. However, the most innovative work on infectious disease spread and global warming (and probably the only other attempt to date to do such research) has been developed by Dobson and Carper[4], who have evaluated the potential spread of trypanosomiasis (sleeping sickness) from western to central Africa given a 2 °C warming scenario. None of the infectious disease work has used sophisticated climatic modeling, and thus the methodologies suggested in this study will concentrate on improving the climatological component within infectious disease studies.

Methodology

The structure of the program

The heat stress/mortality component of this research expands beyond the previous domestic research[11] by assessing the role of extreme weather events on mortality. This is partially accomplished with the use of a new 'synoptic climatological approach,' which evaluates weather situations rather than individual weather elements.

The pollution study concentrates on several U.S. cities with very different climates: Philadelphia, Cleveland, Seattle and Birmingham. The impacts of both weather and air pollution on mortality are investigated, and these results are compared to those obtained in St. Louis through our earlier research[14].

The infectious disease project concentrates on two vector-born diseases: onchocerciasis (river blindness), to be evaluated in western Africa, and malaria, to be studied in Africa and possibly Indonesia.

Procedure: weather/mortality study

Detailed mortality data bases were available for all four evaluated countries (table 1). In the United States, 15 cities were investigated over an 11-year period from 1964 through 1980 (during some intervening years, a sizable amount of information was missing from many records, and those years were not utilized in this study). Ten Canadian cities were examined between the years 1958 and 1988. For both the United States and Canada, daily mortality sums for the summer (June, July, August) and winter (December, January, February) were grouped by age (less than one year, greater than or equal to 65 years, all ages) and cause of death (a weather-related group, including all respiratory causes, influenza, injury, stroke/cerebrovascular and, for summer, heat stroke/heat stress; and a total death group). There is conflicting evidence in the literature about the validity of evaluating specifically weather-related causes of death. Many researchers continue to utilize total mortality figures in their analyses, as deaths from a surprisingly large number of causes appear to escalate with more extreme weather[1,9]. In an attempt to circumvent this apparent disagreement among researchers, weather-related and all causes categories were evaluated separately in this study.

Table 1. Cities evaluated in the study

United States[a]	Canada[b]	China[c]	Egypt[d]
Atlanta	Calgary	Guangzhou	Cairo
Chicago	Edmonton	Shanghai	
Cincinnati	Halifax		
Dallas	Montreal		
Detroit	Ottawa		
Kansas City	Quebec		
Los Angeles	St. John's		
Memphis	Toronto		
Minneapolis	Vancouver		
New Orleans	Winnipeg		
New York			
Oklahoma City			
Philadelphia			
St. Louis			
San Francisco			

Study periods for each country are as follows: [a]1964–1966, 1972–1978, 1980; [b]1958–1988; [c]1980–1989; [d]1981–1985.

For China, mortality data were obtained for Shanghai, which possesses a mid-latitude climate, and Guangzhou (Canton), which has a subtropical climate. Each city contains a central mortuary which receives virtually all of the bodies; a record is kept for each individual. These totals were tabulated daily for summer and winter over a 10-year period from 1980 through 1989. Specific causes of death were not noted, but age groups of greater than 64 years old and total deaths were evaluated.

For Egypt, summer mortality data were extracted for Cairo for a 5-year period from 1981 through 1985. Daily totals were tabulated in the same manner as the Chinese data, although cause of death and age of death were not available.

Two procedures were utilized to ascertain historical weather/mortality relationships, which had to be determined before employing climate scenarios. The first involves the identification of 'threshold temperatures,'

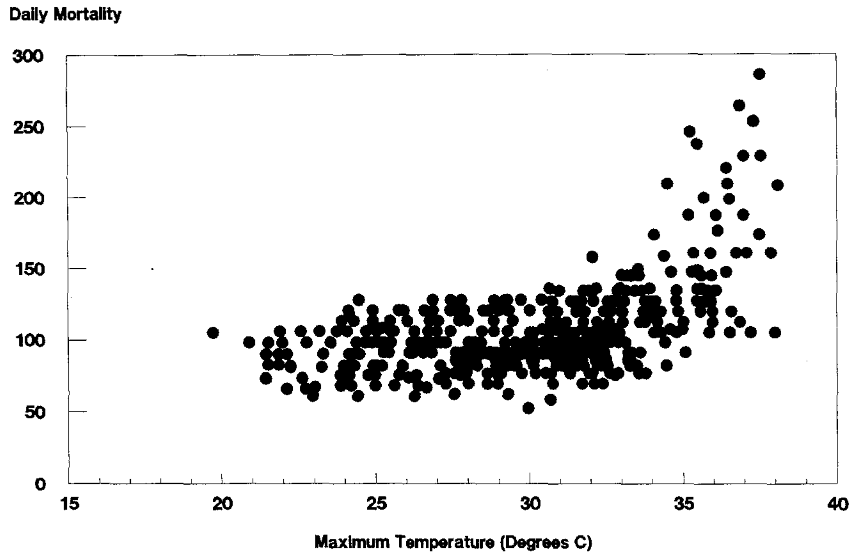

Figure 1. Relationship between maximum temperature and mortality: Shanghai; 1980–89.

which represent the temperature beyond which mortality significantly increases[16]. The second depends upon the identification of offensive synoptic situations, or specific 'air masses' which appear to be associated with particularly high mortality totals[14].

The threshold temperature is calculated objectively by measuring the dissimilarity of mortality rates above and below a given temperature (refer to Kalkstein and Davis[16] for the statistical procedure to calculate the threshold temperature). The threshold temperature in Shanghai, for example, is 34 °C (fig. 1), and mortality increases dramatically at temperatures above this level. The same procedure is repeated in winter, where the threshold temperature represents the temperature below which mortality increases.

Once the threshold has been established, an 'all regression' procedure is used to determine which combination of weather elements (table 2) produces weather/mortality models with the highest coefficient of determination (R^2) for days beyond the threshold temperature[5]. Two non-meteorological independent variables are included within the regression. 'Day in sequence,' which notes how a particular day above the threshold temperature is positioned within a consecutive day sequence, and 'Time,' which determines whether the days occur early or late within the summer season, attempt to evaluate short-term and inter-seasonal acclimatization responses. The algorithms developed through this regression analysis can be employed to estimate present or future deaths attributed to weather if they pass the Box and Wetz criteria for worthwhile predictions[3].

Table 2. Weather variables used in the mortality study

Maximum temperature (Max T)
Minimum temperature (Min T)
Maximum dewpoint (Max DPT)
Minimum dewpoint (Min DPT)
2 pm LST[a] cloud cover (CC 1400)[b]
2 pm LST[a] wind speed (Wsp 1400)[b]
Time of season (Time)
Day in sequence (Day)

[a]LST – Local standard time.
[b]Values represent cloud cover and wind speed measured at 1400 hrs (2 pm LST).

The synoptic procedure, which identifies 'air masses' which may adversely impact human health, requires an entirely different approach. When evaluating the impact of an air mass upon an environmental variable such as human mortality, it is assumed that the variable responds to a set of meteorological elements working in concert, rather than individually. Thus, the synoptic approach assumes that humans respond to the entire 'umbrella of air' which surrounds them, rather than to individual weather elements, such as temperature. In this way, the synoptic procedure permits an evaluation of synergistic relationships among weather elements; it assumes that the combined impact of several elements is different than the sum of the individual impacts of each element.

The synoptic climatological procedure involves development of an automated index which identifies the air mass overlying each city (e.g. continental polar, maritime tropical). A seasonal classification of air masses is developed for each city (except Cairo, due to meteorological data constraints) to categorize each day into its particular synoptic category. This air mass identification procedure, known as the temporal synoptic index (TSI), is designed to classify together data which are considered to be meteorologically homogeneous[14]. Each day is defined in terms of six readily available meteorological elements: air temperature, dewpoint temperature, total cloud cover, sea-level air pressure, wind speed, and wind direction. These elements are measured four times daily, and the developed 24 variables represent the basis for categorization (refer to Kalkstein, Tan and Skindlov, 1987[18] for the procedural framework for TSI).

The mean daily mortality for each synoptic category, along with the standard deviation, is then determined to ascertain whether particular categories have distinctively high or low mortality. Potential lag times are accounted for by evaluating the daily synoptic category on the day of the deaths, as well as one, two, and three days prior to the day of the deaths. Daily mortality is then sorted from highest to lowest during the period of record to determine whether certain synoptic categories (deemed 'offensive') are prevalent near the top or bottom. To evaluate the impact of within-category variations in meteorology for the offensive categories, a stepwise multiple regression analysis is performed on all days within the offensive category utilizing the variables listed in table 2. As with the threshold approach, the algorithms developed through this procedure are used for estimation of mortality if they pass the Box and Wetz criteria.

When measuring the impact of warming on future mortality, the question of acclimatization must be considered. If the globe warms, will people within each locale respond to weather as they do today, or will their reactions be similar to those of people who presently live in hotter climates and are acclimatized to heat? A procedure was developed to account for such acclimatization by evaluating responses in a particular city during heat waves in cool and hot summers. An assumption is made that if people acclimatize, they will respond to heat in a more extreme fashion during cooler summers, when heat waves are infrequent, than in hotter summers, when heat waves are a common occurrence. This assumption is based on previous U.S. research which indicates that acclimatization to hot weather can occur very rapidly in some places, often within one season[15,22]. In addition, recent research in the medical community on the role of heat shock proteins, which are synthesized by many organisms as a response to stresses such as temperature change, suggests the possibility that these proteins could be involved in rapid acclimatization[2].

Thus, a relationship was established for each evaluated city between the number of days within a summer above the threshold temperature (or, for the synoptic approach, within an offensive air mass) and the total mortality for each of these hot days. For example, if more people die per hot day during a cooler summer, and less die per hot day during a warmer summer, this suggests that some degree of acclimatization has occurred during the warmer summer. Thus, it is probable that populations acclimatizing over the span of one summer might also acclimatize to a slow, long-term warming which would be associated with a human-induced climatic change. The effects of climate change on winter-related mortality are more complex and are not estimated here.

If mortality per hot day in a certain city is significantly and inversely related to the number of days above the threshold temperature over a series of summers, it is assumed that the population of this city could acclimatize to the warmer weather expected under doubled CO_2 conditions. For these cities, estimates of acclimatized mortality under the various climate change scenarios are developed and calculated by utilizing the slope of the regression line to estimate diminished mortality during the hotter summers as expressed by the scenarios. Table 3 provides an example of expected monthly temperature increases under doubled CO_2 conditions using the GISS (NASA Goddard Institute for Space Studies) scenario. Typically, the greatest increases are in continental and mid- or high-latitude regions.

It is important to note that these acclimatization estimates only take into consideration physiological and short-term behavioral adjustments, not infrastructure changes such as major architectural improvements in urban areas, to take account of the increased warmth. It is virtually impossible to predict how city structure might change under global warming conditions, and no research involving infrastructure changes has even been attempted. Nevertheless, the acclimatization procedure outlined here may still yield the most realistic estimates, as cultural or social adjustments such as architectural changes, may lag far behind the physiological adjustments of the human body, especially in developing countries[15].

Table 3. GISS doubled CO_2 scenarios for selected cities

City	Country	Location[1]	Projected warming (°C) June	July	August
New York	United States	40°40′N, 73°58′W	+2.6	+3.5	+3.3
St. Louis	United States	38°39′N, 90°15′W	+3.8	+3.7	+4.1
Toronto	Canada	43°40′N, 79°23′W	+3.3	+4.2	+4.2
Montreal	Canada	45°30′N, 73°35′W	+2.6	+3.5	+3.3
Shanghai	China	31°14′N, 121°27′E	+4.7	+4.5	+4.2
Guangzhou	China	23°07′N, 113°15′E	+3.7	+4.0	+2.7
Cairo	Egypt	30°00′N, 31°17′E	+4.0	+3.6	+2.1

[1]Location given in latitude and longitude coordinates.

Table 4. Present-day and future estimates of total summer mortality

	Present mortality (based on test period average)	GISS 2 × CO_2 Scenario Unacclimatized	Acclimatized
United States			
Atlanta	18	159	79
Chicago	173	412	622
Cincinnati	42	226	195
Dallas	19	309	244
Detroit	118	592	295
Kansas City	31	60	100
Los Angeles	84	1654	824
Memphis	20	177	88
Minneapolis	46	142	186
New Orleans	0	0	0
New York	320	1743	880
Oklahoma City	0	0	23
Philadelphia	145	938	700
St. Louis	113	744	372
San Francisco	27	246	202
Canada			
Montreal	69	430	218
Toronto	19	251	3
China			
Guangzhou	135	1569	*
Shanghai	418	3587	*
Egypt			
Cairo	281	1125	*

*Research indicates little chance of acclimatization in the Chinese and Egyptian cities[11].

Results

United States mortality

With the use of algorithms developed from the historical weather/mortality relationships described earlier, estimates of present-day mortality attributed to weather were attempted for summer (table 4). Cities in the northern and midwestern United States showed the greatest response in summer. It appears that weather has a differential regional impact on mortality in summer, and the strongest relationships are found in areas of the United States where high temperatures occur irregularly. In the southern United States, where heat is a relative constant, a much smaller impact is noted[16]. In addition, regression results indicate that the timing of hot weather has an additional impact on mortality. Extremely hot weather occurring early in the season appears to have a more devastating impact than similar weather occurring in August. These differential inter-regional and seasonal responses to weather imply that some degree of human acclimatization to stressful conditions is likely.

There is some debate about the impact of a period of stressful weather upon the entire season's mortality total. There are some who believe that seasonal mortality as a whole does not increase when stressful weather is present, and most of the observed 'extra' deaths associated with the stressful conditions are merely deaths that would have occurred anyway a few days or weeks later. It is our feeling that stressful weather does actually induce extra deaths (i.e. deaths that would not have occurred that season if stressful weather had not been present). This suggestion is based on a cursory evaluation of mortality totals after the occurrence of stressful weather events. After a period of high mortality associated with oppressive weather, mortality rates do not appear to dip significantly below a long-term baseline level. This suggests that the observed mortality peaks represent 'extra deaths' associated with the stressful weather, rather than shifted deaths which would have occurred shortly afterward if the stressful weather had not been present. However, the U.S. Environmental Protection Agency is sponsoring further investigation of this phenomenon to make certain that these mortality peaks are, in fact, extra deaths associated with stressful weather conditions.

The impact of weather on mortality in winter appears to be much less than in summer. Research suggests that overcast, damp, and possibly snowy days may provide conditions for heightened mortality in winter, as people are forced indoors and in closer contact, creating an environment that increases the probability of microbial or viral infection[21]. In addition, differential inter-regional and seasonal responses to winter weather are not apparent.

The summer algorithms were used to estimate future trends in mortality attributed to global warming as predicted by the GISS doubled CO_2 weather scenarios. If one assumes that people do not acclimatize to warmer weather, weather-induced mortality in the United States might increase seven-fold over present levels in the 15 evaluated cities by the year 2060 (table 4). However, this total might be misleading, as some degree of acclimatization is expected to occur. The acclimatized results show a significant but more modest increase in mortality if the earth warms as suggested by the GISS scenario.

Is there a possibility that the increases in mortality determined in this study are really a function of pollution rather than weather? Using the automated synoptic approach, it appears that fluctuations in day-to-day mortality appear to be much more sensitive to weather than to high levels of pollution[14]. Anticyclonic synoptic situations with the highest mean pollution concentrations in St. Louis and other U.S. cities were not associated with unusually high numbers of deaths. Conversely, hot and humid air masses which were associated with the highest daily mortality totals did not possess high mean concentrations of total suspended particulates, ozone, sulfur dioxide, or nitrous oxides.

A more recent unpublished evaluation indicates that the concentration of total suspended particulates and ozone might have a slight impact on human mortality, but only when the weather is not stressful. In this study, a mean daily standardized mortality (expressed as a variation from a daily annual mean) was evaluated for days within

Table 5.
Total suspended particulates/mortality means for maximum temperature above threshold (31 °C) in Philadelphia

TSP categories	N	TSP[a] mean	Mortality[b] mean
bottom 20% TSP	40	58.38	5.68
bottom 20% to 40% TSP	40	73.36	6.08
middle 20% TSP	40	85.99	4.53
top 20% to 40% TSP	40	100.10	6.68
top 20% TSP	40	129.19	6.18

Total suspended particulates/mortality means for maximum temperature below threshold (31 °C) in Philadelphia

TSP categories	N	TSP[a] mean	Mortality[b] mean
bottom 20% TSP	150	39.37	−4.15
bottom 20% to 40% TSP	150	51.95	−3.37
middle 20% TSP	150	62.98	−4.83
top 20% to 40% TSP	150	76.86	−2.55
top 20% TSP	150	102.23	−1.37

[a]Total suspended particulates in micrograms per cubic meter.
[b]Positive and negative mortality values reflect variation around a baseline of zero.

various quintiles of pollution concentration for Philadelphia (tables 5 and 6). On days when temperatures were very warm (over 31 °C), there appeared to be very little difference in mean mortality between the lowest and highest quintile for ozone and total suspended particulates. However, on days when temperatures were cooler, a gradual upward trend in mortality was noted within each higher pollution quintile. Thus, for ozone, mean mortality was approximately four deaths higher within days in the highest quintile than within the lowest quintile (−1.02 vs. −5.24 deaths) when temperatures were below 31 °C. It is possible that a pollution 'threshold' must be achieved before this

Table 6.
Ozone/mortality means for maximum temperature above threshold (31 °C) in Philadelphia

Ozone categories	N	Ozone[a] mean	Mortality[b] mean
bottom 20% ozone	40	0.062	5.40
bottom 20% to 40% ozone	40	0.088	5.18
middle 20% ozone	40	0.105	8.30
top 20% to 40% ozone	40	0.118	6.90
top 20% ozone	40	0.153	4.70

Ozone/mortality means for maximum temperature below threshold (31 °C) in Philadelphia

Ozone categories	N	Ozone[a] mean	Mortality[b] mean
bottom 20% ozone	150	0.043	−5.24
bottom 20% to 40% ozone	150	0.077	−6.15
middle 20% ozone	150	0.080	−3.03
top 20% to 40% ozone	150	0.088	−0.85
top 20% ozone	150	0.093	−1.02

[a]Ozone in parts per million.
[b]Positive and negative mortality values reflect variation around a baseline of zero.

increase is noted. For example, for the total suspended particulate results, there is little difference in mean mortality between the lowest and middle quintile (−4.15 vs. −4.83 deaths). However, a gradual increase is noted within the highest two quintiles.

Nevertheless, this study supports our original finding that weather appears to have a much greater impact on day-to-day mortality than pollution concentration. It is noteworthy that mean daily mortality for *all* quintiles is well above the annual mean during the warmest days (as high as +8.30 for the middle ozone quintile) and well below the mean for all quintiles during the cool days. Considering that pollution concentration has virtually no impact on mortality during the warmest days (mean daily mortality is similar for all pollution quintiles), it is suggested that weather is the primary factor contributing to mean daily mortality values which exceed the annual mean by a considerable margin.

Canadian mortality

Although there appears to be a significant relationship between summer weather and mortality in Canada, there is no doubt that the overall impact is less than in the United States. Using the threshold temperature procedure, only two cities (Toronto and Montreal) of the 10 evaluated demonstrated a strong relationship. The synoptic approach uncovered significant summer relationships for three cities: Toronto, Montreal, and Ottawa. These results suggest that the other Canadian cities do not exhibit the heat intensity found in China and the United States, although it was surprising that results from Winnipeg, Calgary, and Edmonton, which suffer from periodic heat waves, were not significant. The lack of a relationship in these cities might be attributed to the continental, rather than maritime, source of hot air, which may be less stressful. It is also possible that the small size of these cities contributes to a noisier mortality data base, as non-weather induced factors, such as a major traffic accident, can have a large impact on mortality totals. This was also a problem with smaller U.S. cities[10].

Threshold temperatures for Montreal (29 °C) and Toronto (33 °C) were considerably lower than those for most U.S. cities. It may be that these cities represent the present-day northern limit for heat-related mortality in North America, as air masses from tropical sources do intrude occasionally into southern Canada. An evaluation of variables affecting mortality above the threshold temperature indicates strong similarities between Montreal and Toronto. For both cities, the consecutive day variable is directly related to mortality above the threshold, indicating that a long string of stressful days produces an adverse physiological response. For both cities, the time variable is inversely related, implying that heat waves early in the season are more damaging than those late in the season; this corresponds with U.S.

results and implies intra-seasonal acclimatization[10]. For Montreal, there is a direct relationship between minimum dewpoint and mortality, which underscores the importance of hot, humid air masses. For both cities, the coefficient of determination is sufficiently high to pass the Box and Wetz test, indicating that the algorithm developed from the analyses may be used for predictive purposes.

The synoptic evaluation uncovered an offensive air mass for Montreal, Toronto, and Ottawa. The stressful air mass had similar characteristics for all three cities: very warm (by Canadian standards), high dewpoint, moderate to strong southwesterly winds, and anticyclonic control. Thus, it appears that maritime tropical air masses, which are noted for high relative humidity, are important in Canada.

Estimates of present-day mortality using the threshold approach illustrate that several hundred extra deaths can be attributed to stressfully hot weather during typical summers (table 4). These totals are comparable to heat stress-related mortality values for moderately sensitive U.S. cities, such as Los Angeles and Minneapolis[11].

There are strong indications that global warming could significantly increase heat-related mortality if the population does not acclimatize. Non-acclimatized estimates exceed 400 extra deaths in Montreal using the threshold procedure for the GISS scenario (table 4). This value is similar to results from moderately sensitive U.S. cities, such as Dallas and Atlanta[11]. If acclimatization does occur, very little heat-related mortality is expected in Toronto, while Montreal values still exceed 200 deaths per summer.

Chinese mortality

Results suggested that heat may have a very significant impact on human mortality in China, especially in mid-latitude cities. Although the threshold temperatures for Guangzhou and Shanghai are similar (figs 1 and 2), it is quite obvious that the rise in mortality above the threshold is much more dramatic for Shanghai. This finding of a more distinct mortality response in the mid-latitude city is consistent with research conducted in the United States indicating that northern and continental cities, which experience severe but non-constant heat, are more sensitive to heat stress-related mortality than southern cities, where extreme heat is routine.

In Shanghai, regression analysis indicates that days with hot afternoon temperatures, low wind speeds and low humidity are associated with the greatest mortality increases. For Guangzhou, hot afternoon temperatures and very warm nights are related to the greatest mortality, with wind speed and humidity being insignificant. In addition, hot weather early in the summer season in Guangzhou was associated with greater mortality than similarly hot conditions later in the season, a result consistent with U.S. findings. However, the results for Guangzhou, although statistically significant, were considerably less robust than those for Shanghai.

Direct mortality comparisons between Shanghai and Guangzhou indicate significant differences in response between the two cities (table 7). Although more days are above the threshold temperature at Guangzhou during an average summer, total deaths and death rates on hot days are considerably greater at Shanghai. In fact, the average death rate at Shanghai on days above the threshold (1.972 per 100,000 population) is 59 percent greater than Guangzhou (1.240 per 100,000). During an average summer, heat stress-related deaths are three times higher in Shanghai than Guangzhou (418 vs. 135), representing a death rate that is 50 percent higher. In addition, the Shanghai heat stress-related

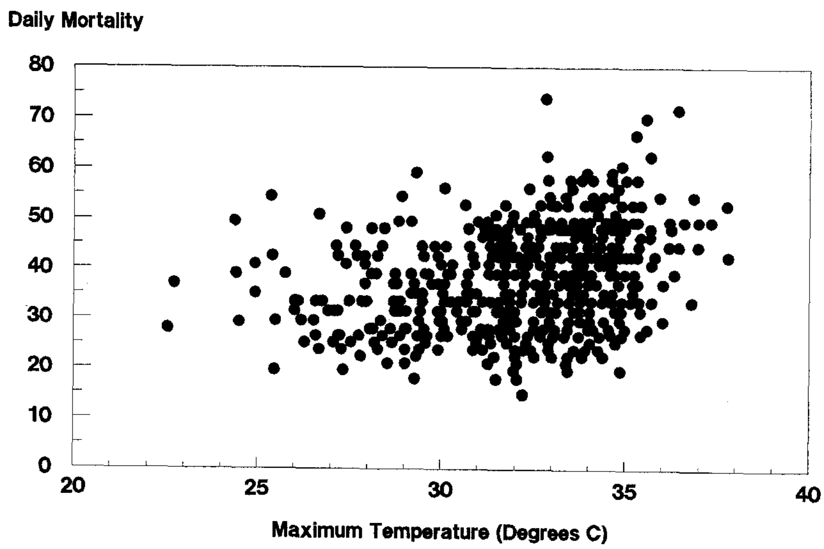

Figure 2. Relationship between maximum temperature and mortality: Guangzhou: 1980–1989.

Table 7. Summer mortality analysis: Shanghai and Guangzhou

Category	Shanghai	Guangzhou
Daily deaths in an average summer	103.3/1.524[a]	36.6/1.118
Threshold (maximum) temperature	34 °C	34 °C
Days meeting threshold per year	12	25
Percentage of days over threshold	13%	28%
Daily deaths on hot days	133.6/1.972	40.6/1.240
Heat related deaths in an average summer[b]	418/6.19	135/4.126
Heat related deaths in the hottest summer	1140/16.825	216/6.602

[a]Actual deaths/death rate per 100,000 population.
[b]The difference between the computed number of deaths by the regression on days above the threshold and the average of the regular days.

death rate is 132 percent higher than New York's, which is one of the most sensitive U.S. cities.

The synoptic evaluation for the two cities revealed two potentially offensive air masses at Shanghai (table 8), but no particular air mass appears related to increased mortality in Guangzhou. Air mass 1 in Shanghai, characterized by hot, clear, and dry conditions, exhibited a mean daily mortality about 9 percent above the total mean. However, although this air mass occurs on only 14 percent of summer days, it is present over one-third of the time in the 50 highest mortality days recorded in Shanghai during the sample period. Air mass 2 in Shanghai, associated with sultry maritime tropical conditions, appears to be even more stressful. This air mass was present during 60 percent of the top 50 mortality days, which is remarkably high considering that its normal summer frequency is less than 18 percent. Thus, the combination of these two apparently stressful air masses, which occur less than 33 percent of the time during summer, are present during 47 of the top 50 mortality days in Shanghai (94 percent). Using the GISS $2 \times CO_2$ scenario, these air masses occur much more frequently. For example, air mass 2 is estimated to almost double in frequency, from 17.9 percent to 32.7 percent, using the GISS scenario. This may affect heat stress-related mortality in Shanghai very negatively.

The winter evaluation indicates that extreme cold has little impact on daily mortality in both cities. Although mean daily mortality is slightly higher in winter than in summer, no significant weather/mortality relationship could be determined for either city. No mortality peaks are observed at low temperatures, and the slightly higher general winter mortality is attributed to influenza and other infectious diseases not directly related to cold. Thus, potential changes in winter weather under various global warming scenarios should have an insignificant impact on weather-related mortality.

It appears that human-induced climate change could have a very large negative impact on heat stress-related mortality, especially in Shanghai (table 4). Assuming no acclimatization and using the threshold approach, heat stress-related mortality for the city under the GISS scenario exceeds 3500 deaths, which represents an eight-fold increase over present conditions. This value is considerably higher than any U.S. city.

There is evidence indicating that acclimatization will not be a major factor in either Chinese city. Thus, it is likely that the weaker mortality response at Guangzhou is a function of the small climatic variability which occurs there in summer, rather than any acclimatization factor. The GISS climate change scenario utilized in this study assumes that climatic variability will not change in either city. If this is the case, Shanghai's summer climate will become warmer, but the variability will not be reduced. Thus, if this is true, the implication is that intense but irregular heat waves will continue to occur in Shanghai, lessening the probability of population acclimatization.

Egyptian mortality

An evaluation of maximum temperature/mortality relationships in summer for Cairo for the period of 1981 to 1985 demonstrates that mortality from all causes increases quite rapidly as the temperature increases (fig. 3). Interestingly, the relationship between these variables indicates that a threshold temperature cannot be determined for Cairo, even though it is obvious that a

Table 8. Offensive air masses in summer for Shanghai

Air mass type	1	2
Weather	Hottest in the season, light winds from SE, little cloudiness, comparatively high atmospheric pressure (subtropical anti-cyclone dominant)	Almost as hot as air mass 1, very light wind from SE at night and from SW by daytime, mostly cloudy, low atmospheric pressure (maritime tropical air mass)
Mean daily mortality	113.9	116.9
Percent above overall mean	8.8%	11.2%
Percent of all summer days	14.2%	17.9%
Days in top 50 highest mortality days/percent	17/34.0%	30/60.0%
Percent frequency of air mass under GISS $2 \times CO_2$ scenario	18.4%	32.7%

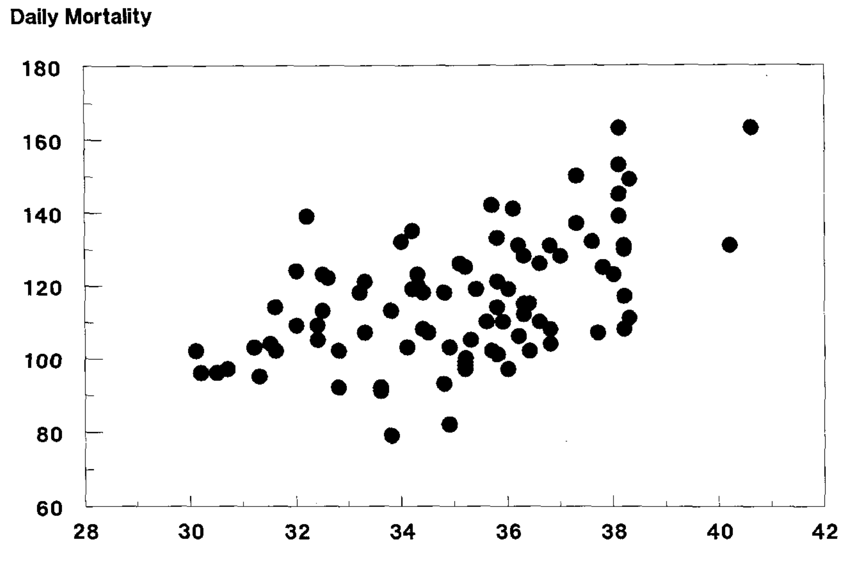

Figure 3. Relationship between maximum temperature and mortality: Cairo, Egypt: 1982.

strong temperature/mortality relationship exists. The threshold result is unique to Egypt only, as all other cities with a strong weather/mortality relationship exhibit a distinctive threshold temperature. Additionally, Cairo's response differs from results obtained in Phoenix, Arizona, which exhibits a summer climate even more extreme than Cairo's. In Phoenix, no significant weather/mortality relationship was uncovered, possibly because of the population's easy access to air conditioning. However, the role of air conditioning in mitigating heat-related mortality is especially complex, and there is a disagreement in the literature as to whether air conditioning is helpful at all[10].

Although weather variables other than maximum temperature were unavailable for this particular evaluation, several other interesting features were noted in the Cairo study. First, the timing of hot weather through the season has little impact in Cairo. Thus, a very hot day in August contributes to mortality just as strongly as a similar day in June. This is dissimilar to results in most other locales, where heat early in the season has a much greater impact than if it occurs later. Second, consecutive hot days do not seem to exacerbate heat-related mortality. This also differs from Chinese, Canadian, and U.S. results, where the impact of heat increases with increasing duration of heat. Third, the impact of hot weather on heat-related mortality is similar regardless of whether the season is hot or 'cool'. This is similar to results in China but differs from those in North America, and implies that acclimatization may not be a major issue in Cairo. Estimates of present-day heat-related mortality for Cairo number almost 300 individuals during an average summer, which is higher than any U.S. or Canadian city evaluated, but lower than Shanghai's (table 4). Estimates of present-day heat-related mortality during the hottest year with available data (1981) approach 400 people, but it should be noted that the five-year period evaluated did not include any extremely hot years. Thus, during certain summers in Cairo, it can be expected that heat-related mortality would be much higher.

Estimates utilizing the climate scenarios indicate that Cairo may be vulnerable to very large increases in heat-related mortality if the globe warms (table 4). Analysis based on a GISS scenario shows that average summer totals exceed 1000, which is higher than most evaluated U.S. or Canadian cities. However, rates and totals are considerably less than those estimated for Shanghai.

A comparison of Cairo's heat-related mortality rates with other major cities in the United States, Canada, and China reveals the city's comparative sensitivity to hot weather (table 4). Much like the Chinese cities, the lack of a differential mortality response during hot and cool summers suggests that acclimatization may not occur in Cairo. Thus, it is quite likely that Cairo's heat-related mortality rate will increase by three- or four-fold under the various scenarios. It is possible that the consistency of hot weather, as expressed by a low variation in day-to-day maximum temperatures, may help mitigate heat-related mortality. However, it is possible that rising temperatures might place Cairo's summer weather outside the range of human tolerance; if this is the case, mortality rates could be considerably higher.

Infectious diseases

Two vector-borne infectious diseases, onchocerciasis and malaria, have been selected for evaluation. Sites in several western African countries that represent numerous environments have already been selected for the onchocerciasis study. The blackfly vector population, which transmits the disease, has been monitored at these sites for up to 18 years. In addition, meteorological data and streamflow measurements in western Africa are readily available.

The onchocerciasis evaluation has commenced, and study sites have been selected in Benin, Togo, Ghana, Senegal, Mali, and Burkina Faso. The study design is based on vector blackfly populations rather than on humans afflicted with the disease. The goal of the onchocerciasis project is to determine the climatic-limiting factors of the vector for the purposes of estimating future blackfly populations and determining potential shifts in the range of the insect under the various global warming scenarios.

A climatic water budget approach, which provides for streamflow estimates, will be one of the necessary methodologies for determining insect/climate relationships considering that the blackfly's life cycle and reproductive rate are closely related to the magnitude of streamflow. Various water budget procedures are available which can be applied directly to GCM data, such as the Thornthwaite/Mather water budget[20]. However, a synoptic evaluation or some other approach which evaluates thermal and other atmospheric variables will also be necessary to determine climatic limiting factors which are not directly related to streamflow.

The malaria project is less well defined at this time, although data sources for western and central Africa have been identified. It appears that the dependent variable in the malaria study will be numbers of afflicted individuals, rather than the type of vector assays which will be utilized in the onchocerciasis study. Considering that the incubation time of malaria within the human host is fixed (approximately 21–30 days), while the onset of first symptoms of onchocerciasis is highly variable (up to 18 months after an infected blackfly bite), it is much more feasible to deal with afflicted individual data for the malaria project.

Conclusions and recommendations for future research

There are numerous uncertainties surrounding the estimates presented in this report. For example, can an acclimatization procedure be developed which describes more accurately potential social and infrastructure changes which would be associated with global warming? How will changes in the range of important vector-borne diseases contribute to human migration patterns? The following studies are suggested to address these and other unanswered questions:

1) The potential impact of pollution on heat stress-related mortality in Egypt and China. For both developing countries, it has been assumed that changes in mortality are dependent upon climate alone. Although pollution had only a minor impact on acute mortality in the United States, it is possible that in areas with limited emission controls, climate and pollution concentration may have a synergistic effect on mortality.

2) The impact of acclimatization on heat stress-related mortality. Results here suggest that humans might acclimatize to increased heat, especially in Canada and the United States. However, acclimatization impacts in developing countries are more nebulous, and social scientists from these countries should be included in a future study to determine potential infrastructure changes which could alter the mortality results.

3) The impact of infectious disease spread on demographics. This study would concentrate on migration patterns, changes in population age distributions, and other demographic impacts which may occur if certain infectious diseases spread to other nations.

4) The impact of global warming on other infectious diseases. The present study concentrates on only two diseases, but other vector-borne ailments, such as yellow fever, dengue fever, schistosomiasis, and trypanosomiasis, kill millions of people in developing nations and may expand in range if the globe warms. With the successful development of climate/disease models for onchocerciasis and malaria, an effort should be made to uncover climate/disease relationships for other equally dangerous infectious diseases.

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