THE IMPACT OF HEAT ISLAND REDUCTION STRATEGIES ON HEALTH-DEBILITATING OPPRESSIVE AIR MASSES IN URBAN AREAS: A FOLLOWUP STUDY

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Introduction

In 2003, the Center for Climatic Research at the University of Delaware (CCR) received funding from the U.S. EPA Heat Island Reduction Initiative (HIRI) program to determine if the number and/or severity of days that are detrimental to human health within selected urban areas would decrease if heat island reduction measures were instituted (Kalkstein and Sheridan, 2003). In addition, the CCR estimated the change in heat-related mortality, assuming these measures were in place. The measures include an increase in surface albedo, and in some cases, an increase in urban vegetation cover within areas of the cities most vulnerable to heat-related health problems. There is copious research indicating that these alterations can have a major positive impact on the urban landscape, including: lowering both indoor and outdoor temperatures, improving air quality, lessening energy utilization, and generally improving human health (Taha, 1997; Konopacki and Akbari, 2002; Kalkstein and Sheridan, 2003).

Four cities were chosen for examination in this study: Detroit, Los Angeles, New Orleans, and Philadelphia. The cities were selected because they represent diverse climates and potentially react differently to the heat island mitigation measures being evaluated here. In addition, two of the four cities are presently utilizing our heat/health watch warning systems as part of their strategy to lessen the negative health impacts of heat (Kalkstein et al., 1996, Sheridan and Kalkstein, 2004). Thus, we can communicate our findings to important stakeholders in those cities with whom we have close relations.

We utilized a synoptic climatological approach to identify those air masses that have been historically associated with statistically significant increases in heat-related mortality. We identified a dry tropical air mass (DT), which has the distinctive meteorological attribute of being the hottest air mass found in these cities. In addition, this air mass possesses low humidity and most often, cloudless skies that permit heating of urban buildings. In addition, two particularly oppressive subsets of the moist tropical air mass (MT+ and MT++) were also noted to be associated with elevated heat-related mortality. This air mass is not as hot as DT, but possesses a much higher relative humidity, which often lessens the ability of the human body to effectively lose heat through sweating.

The results are summarized in Table 1.

Table 1

A Summary of Results

Attribute	**Detroit**	**Los Angeles**	**New Orleans**	**Philadelphia**
Scenarios Constructed	High Albedo High Vegetation High Albedo + High Vegetation	High Albedo Moderate Albedo + High Vegetation	High Albedo High Vegetation	High Albedo High Vegetation
Offensive Air Masses	DT MT+	DT MT+	MT+ MT++	DT MT+
Meteorological Changes with Cooling Scenarios	Very little, some minor morning temperature decreases especially with high vegetation.	Significant temperature decreases especially afternoon with high albedo scenario, some dewpoint decreases with high albedo.	Very little, with some minor increases and decreases.	Some moderate afternoon temperature decreases especially with high vegetation.
Number of Days with Air Mass Changes	1 change to more oppressive air mass (17 total days).	4 changes to less oppressive air mass (all high albedo), 1 change to less oppressive air mass (moderate albedo plus high vegetation) (18 total days).	1 change to less oppressive air mass (11 total days).	2 changes to less oppressive air mass (18 total days).
Mortality Changes	Very little, some minor decreases, some minor increases.	Significant for 2 of 4 heat waves with high albedo (about 20 percent reductions), moderate for a third heat wave (about 5 percent reduction), results unimpressive with moderate albedo/high vegetation.	Very little, one air mass day change reduced mortality by 3.	Moderate decrease for 2 or three evaluated heat waves; reductions about 15%.

(source, Kalkstein and Sheridan, 2003)

There were strongly differing responses among the four cities when albedo and vegetation cover were modified. In Philadelphia and Los Angeles, there appeared to be some significant downward change in mortality, mainly because some days demonstrated air mass alterations due to the modified conditions (particularly in Los Angeles during humid heat waves). In Detroit, changes were more modest, with some slight mortality decreases noted except for one day where the higher vegetation scenario led to an air mass change to a more humid MT+ and associated mortality increases. In New Orleans, responses were minimal except for one day that experienced an air mass change from MT++ to a less offensive MT+.

In addition, the study suggested that the high albedo scenarios are more effective in lowering mortality than the high vegetation scenarios in three of the four cities, but high vegetation seemed more effective in Philadelphia. Neither increasing albedo nor vegetation produced the dramatic results that we would have hoped for in New Orleans and Detroit, but nevertheless, in both Philadelphia and Los Angeles, several of the days demonstrated air mass changes, particularly on days that were originally hot and very humid, that led to significant decreases in mortality. We were particularly impressed with the Los Angeles results, especially for the high albedo scenario.

One interesting finding was the differential inter-regional responses to the modifications among the locales. Since we only evaluated one city within each region (East, Midwest, South, West), it is not known if this inter-regional differentiation was attributed to the general meteorology of each region or some specific factor inherent to each city evaluated. With this in mind, before the results of this study can be considered conclusive, we recommended a duplication of the analysis in four additional cities within the same regions. For example, if this evaluation is replicated in New York City, and if responses are similar to those that were already found in Philadelphia, we can say with more certainty that there is a particular response in the East that is constant throughout the region. This would be an important finding, since the Philadelphia evaluation seems to suggest that increasing albedo and vegetation leads to some significant mortality reductions. The same holds for the other cities; in New Orleans, we found little mortality response regardless of albedo or vegetation conditions. Is it possible that the South responds less dramatically than the East? Or is it possible that New Orleans represents some kind of anomaly? If we replicate this study in a city with a similar summer climate as New Orleans, for example, Houston, we may gain the answer.

The goal of this evaluation is to therefore replicate this study in four additional cities and to compare the results with the four cities evaluated in the initial 2003 study. The four cities chosen were New York, NY; Baltimore, MD (to compare with the Philadelphia results); Chicago, IL (to compare with the Detroit results); and Houston, TX (to compare with the New Orleans results). A comparison with Los Angeles was deemed difficult because the climates of large cities remotely near Los Angeles are quite different (e.g. San Diego, which experiences many less severe Santa Ana days, and Bakersfield, which is too small in population and much hotter than the Los Angeles area).

Methods

In the first study, two of the four cities employed state-of-the-art operational heat-health systems (Philadelphia and New Orleans; Sheridan and Kalkstein, 2004). In this evaluation, only one of the cities (Chicago) is utilizing such a system. These systems are designed to reduce heat-related mortality regardless of any urban modification, and thus, the deployment of a heat/health system will have no impact upon the results of this study. However, cities using the system are more acutely aware of the heat/health problem, and are thus more likely to implement mitigating urban landscape modification techniques.

For each of the cities examined, the weather – mortality relationship was determined by the past response of the local population to different weather conditions. The initial step in this process was the standardization of both mortality and weather data. Mortality data are available for the entire US in digital format for the period 1975 to 1998 (National Center for Health Statistics, 2001). As this research focuses on heat, only the "summer" period, May 1 to September 30, was analyzed for each year. For each day, total mortality across the city's metropolitan area was summed. These mortality totals were then standardized to account for demographic changes in the population characteristics over the 24-year period, including population aging and growth or a decline in the overall death rate for reasons unrelated to weather (e.g. in Rome, people leave the city in August to go on holiday, lowering the daily mortality significantly – this decrease must be included in standardization as it represents non-meteorological "noise").

Standardization proceeded on two levels. First, mean daily summer mortality was evaluated for the 24 year period, and a trend line was fit to these data. If there was a statistically significant trend, the data were standardized about this trend line, which generally reflects population growth in the urban area. Three of the four cities (all but Baltimore) were standardized because of an increasing mortality trend. At this level, nothing was done to determine whether an increasingly aging population is increasing general demographic sensitivity to heat; clearly, this is an addition to be made in the future. Second, an inter-seasonal standardization of mean daily mortality was developed. There is often a sizable inter-seasonal change in mortality that has to do with social/cultural factors, such as vacations and holidays (such changes are considered “noise”, as they pollute the trends associated with weather). These are accommodated for by fitting a cubic spline to the trend existing in the inter-seasonal mean daily mortality data. This was done for all four cities.

Standardization yielded a value of “anomalous mortality” above or below the established trend lines described above for each day in the period of record for each city. Thus, with considerable non-meteorological noise removed from the mortality data, evaluations proceeded using the newly-created anomalous mortality variable.

The weather data were supplied by NOAA’s National Environmental Satellite, Data, and Information Service (2000) and are standardized by an air-mass classification procedure. This procedure determines which of several air masses has occurred over a particular city on a particular day, and accounts for the time of year by standardizing for seasonal variability in meteorological conditions. For this research, the Spatial Synoptic Classification (SSC) was utilized (Sheridan, 2002), which represents our latest iteration to develop a state-of-the-art air mass classification procedure. The SSC places every day into one of a number of air mass types listed below. The procedure commences by selecting “seed days”, or days in each locale that are most representative of each air mass type. This requires a priori information about the meteorological character of each air mass, something that we, as synoptic climatologists, have considerable knowledge about. We set a range of thermal, moisture, and other conditions that we know to be typical of each air mass at a locale. Then, days are selected that most closely match these conditions, and these are designated as the “seed days". Thus, each air mass type is represented by a small subset of days that we know best represent each of the types at each locale.

Once the seed days are selected, all of the remaining days are placed into an air mass group based on a "nearest neighbor" approach described in Sheridan (2002). Thus, through tests of similarity, we determine which group of air mass seeds a particular day is closest to. The procedure even has the ability to determine how good a fit the particular day is; for example, is a day very close to the typical meteorological character of a particular air mass, or is it somewhere between two air mass types?

The SSC procedure required the input of observations of the following weather parameters at each city, four times a day:

- Temperature,
- Dew point,
- Barometric Pressure,
- Wind Speed and Direction, and
- Cloud Cover.

Each of these parameters is weighed somewhat similarly (i.e. there is no exposure to procedures like principal components analysis to determine the role each parameter plays in explaining meteorological variance), and through considerable testing, the final categorization of days is robust both spatially and temporally.

The following are the air mass types within the SSC:

- Dry Polar (DP)
- Dry Moderate (DM)
- Dry Tropical (DT)
- Moist Polar (MP)
- Moist Moderate (MM)
- Moist Tropical (MT)
- Moist Tropical Plus (MT+)
- Moist Tropical Double Plus (MT++; New Orleans only)
- Transition (TR)

The mean meteorological characteristics of these air masses for July are illustrated in Table 2.

TABLE 2
Mean July Air Mass Characteristics for the Evaluated Cities

BALTIMORE	**DM**	**DP**	**DT**	**MM**	**MP**	**MT**	**MT+**	**TR**
5PM Temperature (°C)	29.5	25.4	34.9	25.5	18.9	30.6	33.7	28.1
5AM Temperature (°C)	18.3	16.2	21.8	21.0	18.9	22.0	24.5	20.4
5PM Dew Point (°C)	14.6	11.8	16.8	20.3	16.5	20.5	22.0	16.3
Cloud Cover (tenths)	3.3	4.0	2.7	8.8	9.4	5.5	5.2	5.5

CHICAGO	**DM**	**DP**	**DT**	**MM**	**MP**	**MT**	**MT+**	**TR**
5PM Temperature (°C)	29.1	24.1	34.9	25.0	19.2	30.4	33.0	26.7
5AM Temperature (°C)	16.7	14.0	22.2	20.1	16.7	22.0	24.5	19.3
5PM Dew Point (°C)	15.3	11.9	17.2	18.3	15.0	20.4	22.3	16.4
Cloud Cover (tenths)	3.2	2.9	2.2	7.5	8.7	5.4	5.0	5.5

HOUSTON	**DM**	**DP**	**DT**	**MM**	**MP**	**MT**	**MT+**	**TR**
5PM Temperature (°C)	32.8	-	36.1	28.3	27.0	33.1	35.0	34.8
5AM Temperature (°C)	21.8	-	24.5	21.1	23.2	24.1	26.7	24.2
5PM Dew Point (°C)	18.6	-	18.7	17.8	22.4	22.0	22.3	20.3
Cloud Cover (tenths)	3.5	-	2.8	6.5	7.9	4.6	4.0	4.0

NEW YORK CITY	**DM**	**DP**	**DT**	**MM**	**MP**	**MT**	**MT+**	**TR**
5PM Temperature (°C)	28.0	24.0	33.7	23.8	18.4	29.2	32.2	27.2
5AM Temperature (°C)	20.0	17.8	24.8	20.8	18.0	23.2	25.5	21.6
5PM Dew Point (°C)	13.0	12.1	16.8	18.5	16.1	19.7	21.2	14.6
Cloud Cover (tenths)	3.2	5.0	3.7	8.7	9.8	5.9	5.5	5.3

The DP air mass is associated with relatively cool, dry weather originating from upper latitudes of continental North America. Overnight temperatures are very comfortable, and humidity is not a problem. Skies are usually clear to partly cloudy. DP air rarely reaches Houston, and as Table 1 indicates, is absent there in the summer.

The DM air mass is generally warmer than DP, and is associated with pleasant dry summer weather. While the DP source region is central Canada, DM air originates west of the Rockies, and it is dried and warmed adiabatically as it travels eastward and descends the mountains. There is little human stress associated with either DM or DP air.

DT is an oppressively hot and dry air mass that originates over desert regions of the U.S. and Mexico. It is transported eastward in summer when there is a more active than normal subtropical jet stream. This permits a relatively unmodified version of DT to make its way to the major metropolitan areas of the Midwest and East. When East Coast temperatures top 100 degrees, DT is the responsible air mass. Low moisture content diminishes the specific heat of the atmosphere, permitting a rapid temperature warmup similar to that found over deserts.

MM is an uncommon summer air mass often associated with stationary fronts extending east-west across a region. This air mass is associated with rather cool, humid conditions and overcast skies. Often, this air mass is described as “frontal overrunning”, where warm, humid tropical air overlies denser cool and moist air, creating an atmospheric inversion. This air mass is generally non-consequential in summer.

MP is an even cooler version of the MM air mass, and occurs well to the north of a mid-latitude cyclone and associated front. Winds are generally from the east around the southern flank of a cool polar high pressure center. Skies are overcast, and precipitation is often associated with this air mass. It is very rare in summer and quite common in winter; New Orleans has no MP air in July.

The MT air mass is an uncomfortably hot and humid condition frequently occurring during summer. The air mass is often associated with the well-known subtropical “Bermuda high”, and upper level steering currents are weak, often permitting this condition to last for a number of consecutive days.

A more extreme subset of this air mass is MT+, which possesses a higher temperature and dewpoint than MT. Like DT, this air mass is often associated with statistically significantly higher mortality. Temperatures are not quite at DT levels but are nevertheless warm, with average 5PM readings exceeding 32 degrees C (90 degrees F) at all locations but Los Angeles. Excessive dewpoints inhibit human sweat evaporation rates, and create very uncomfortable conditions. MT++, an even more extreme subset of MT that infrequently occurred in New Orleans, did not appear in any of the cities within this evaluation.

The final air mass type is Transition (TR), which is really not an air mass at all, but a transition from one air mass type to the next. TR most frequently occurs with frontal passages. Considerable European research has indicated that the TR air mass has a negative impact on human health (McMichael et al., 1996), but our research has been unable to find any heat-debilitating indications within TR.

Mean anomalous mortality was then calculated for the occurrence of each weather type. In all four cities, the DT and MT+ air masses were associated with the greatest increase in mortality above normal levels, although the degree of increase varied from one city to the next. These same weather types were also associated with the greatest variability in observed mortality, indicating that, although most of the highest mortality days occur during these “offensive” air masses, there are some days within these air masses that do not have elevated mortality. To account for this variability, a stepwise linear regression equation was developed for the offensive air masses in each city to predict excess mortality. These equations included the following variables:

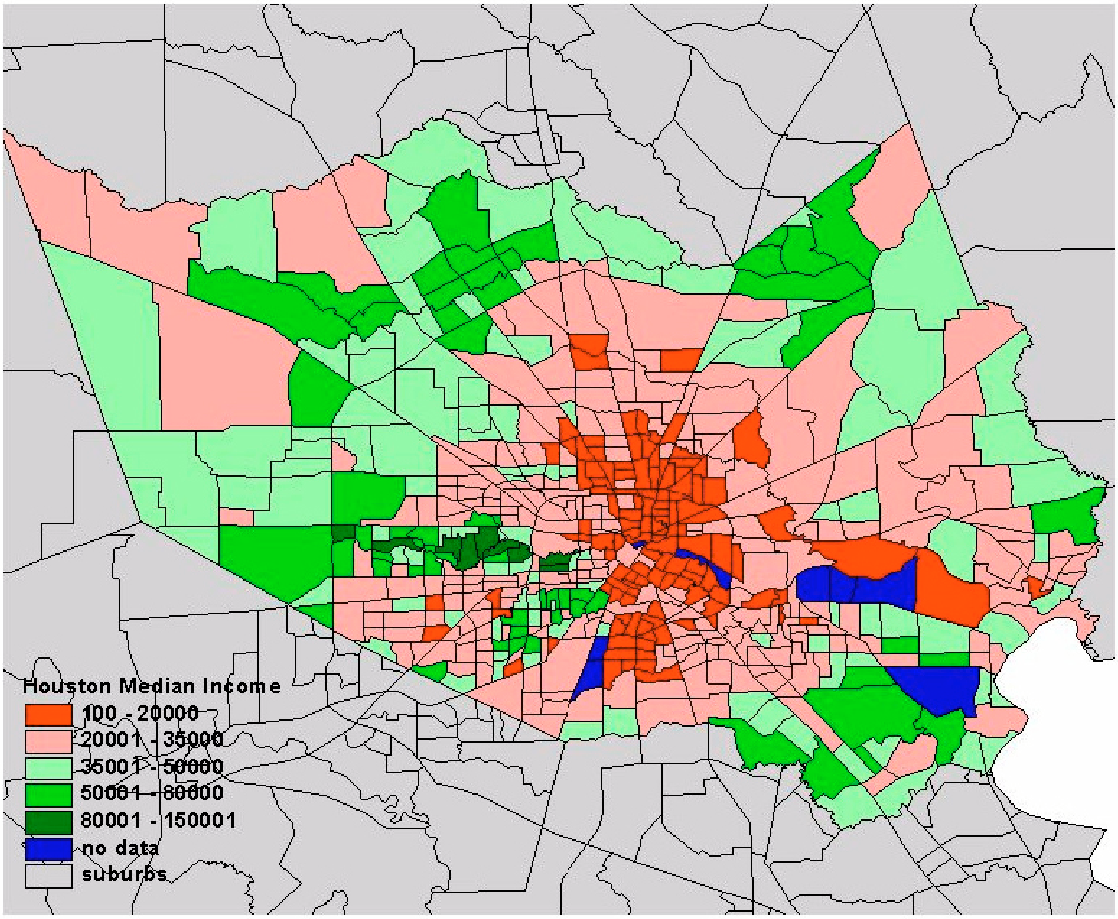
- Time of season,
- Persistence of an oppressive air mass, and
- Air mass character, including temperature, humidity, and cloud cover.

Persistence was determined by a "consecutive day variable"; each consecutive day of an offensive air mass increased this number by 1. So the third consecutive day of an offensive air mass was assigned a value of 3; this variable proved to be a highly statistically significant impactor on daily mortality. In some cases, warm, non-offensive air masses were imbedded within the evaluated heat waves. Air masses like DM can cause some excess deaths if they are surrounded by offensive (DT and MT+) air mass days. Thus, the algorithm was also run for non-offensive air mass days within the heat waves. The consecutive day variable would be decreased by 1 for each non-offensive day within the heat wave. So, for example, a series of consecutive days with MT+, DT, DM, DT, and DT would exhibit a consecutive day variable string of 1, 2, 1, 2, 3.

To test the impacts of alternate urban surface albedo and vegetation upon mortality estimates, MM5-derived meteorological model data for several different scenarios were provided by Dr. Haider Taha, previously with Lawrence Berkeley National Laboratory and now with Altostratus (Taha, 2004). The MM5-derived model data permit us to determine air mass type and character after assumptions are made regarding increased albedo because of the possible addition of reflective surfaces, and changes in surface structure and energy disposition because of added urban vegetation. Variables provided to us from Dr. Taha (including temperature, dewpoint, windspeed and direction, and cloud cover at least four times each day) allowed us to redevelop the air mass classification for each of the cities using the model data.

We provided Dr. Taha with the locations of urban areas within each city that possessed a majority of the population most vulnerable to heat-related morbidity and mortality (usually the poorest sections of the city in terms of economics and housing stock – refer to Figure 1 for an example).

FIGURE 1
Houston Focus Area (in red) Used for Analysis



(source, Taha, 2004)

Three modification scenarios were considered in this study: "high albedo", "high vegetation", and "increased vegetation and albedo". The levels of increase were based on the proportions of seven different urban categories located within the most vulnerable urban areas (Taha, 2004):

- Residential
- Commercial services
- Industrial
- Transportation/Communication
- Industrial and commercial
- Mixed urban or built up
- Other urban or built up

The proportions of these areas used within this study were not specific for each city, but were an average value for all major cities.

To develop the model scenarios, certain levels of albedo increase were assumed for each of the surface types above (Table 3):

TABLE 3.
Assumed levels of albedo increase per surface type (accounts for effects of weathering and soiling)

Surface Type	Increase in albedo		
	Moderate increase	**Large increase**	**Typical base value**
Residential roofs	0.10	0.30	0.15
Commercial roofs	0.20	0.40	0.20
Roads	0.15	0.25	0.10
Sidewalks/Driveways	0.10	0.20	0.15
Parking lots	0.15	0.25	0.10

(source, Taha, 2004)

The “large increase” values were used for the high albedo scenarios, and the “moderate increase” values were used for the increased vegetation and albedo scenarios. For the vegetation modification scenarios, the basic assumptions involve adding a number of trees to each land use category. This translates into a percentage increase in vegetation cover for each category, as described in Table 4. The “moderate increase” in vegetation percentage was used for the increased vegetation and albedo scenarios, while the “large increase” was used in the high vegetation scenarios.

TABLE 4.
Scenarios for vegetation cover increase (as % of 200-m cells)

USGS LULC		**Moderate**	**Large**
Urban categories			
11	Residential	9%	18%
12	Commercial Services	9%	18%
13	Industrial	4%	8%
14	Transportation/Communication	2%	4%
15	Industrial and commercial	6%	12%
16	Mixed urban or built up	5.5%	11%
17	Other urban or built up	5.5%	11%

(from Taha, 2004)

For more specific information on the assumptions utilized in the meteorological modeling for the urban areas, please refer to Taha, 2004.

When comparing the results of this study to those from the previous study (Kalkstein and Sheridan, 2003), it should be noted that the modeling of three of the four cities in the original study was performed by Dr. David Sailor of Portland State University. Dr. Taha only modeled Los Angeles in the original study. Although both researchers used similar assumptions and the same MM5 model, some differences between their methodologies may exist. Thus, care should be taken when making a comparison between all eight cities.

All of these scenarios estimate the microscale changes in atmospheric temperature, dew point, and wind in each city due to albedo enhancement and increasing vegetation. The modifications were then entered into the weather – mortality model, to predict:

- Whether the day remains within an offensive air mass, and if so,
- The change in estimated anomalous mortality due to different weather conditions.

Air masses are mesoscale meteorological features, and thus, the same air mass virtually always exists over the entire modeled area. There are no scale issues to deal with; any changes in meteorology suggested by the MM5 model are directly inputted into the SSC, and a determination is then made as to whether the changes were significant enough to cause an air mass shift.

Results: Meteorology Changes

Four heat waves were evaluated for each of the cities. For New York and Baltimore, the same heat waves were evaluated for both cities, so a comparison could be developed for these cities that possess similar climatic regimes (Figures 2 and 3).

In addition, two of the three heat waves evaluated for Philadelphia in our previous study were utilized for Baltimore and New York as well (early and late July, 1999). Of the four heat waves evaluated for Baltimore and New York, the event of early July, 1999 was the most extreme, with the hottest afternoons and the highest dewpoint temperatures. This event is of an approximate 8-10 year event for the cities, so it is unusual. The remaining three events are more typical, and represent the types of heat events that would occur every year or two in the cities.

For Houston, two of the heat waves that were employed for the New Orleans study were utilized (Figure 4; late May early June, 1998, mid-June, 1998). The dry, hot conditions of the July, 2000 heat wave are an approximate 5-year event. The other events are more typical, especially the 1995 heat wave, which can occur once or twice a year.

FIGURE 2

NEW YORK CITY

	Control						Moderate Vegetation & Albedo Inc.						High Vegetation Increase						High Albedo Increase					
Date	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort
7/4/1999	27.8	33.9	23.3	39.3	MT+	28.3	27.8	33.3	23.1	38.6	MT+	28.0	27.8	33.4	23.3	38.9	MT+	28.1	27.8	33.0	22.8	38.2	MT+	27.9
7/5/1999	30.0	36.7	22.2	41.4	DT	37.2	29.9	35.9	21.5	40.1	DT	36.8	29.9	36.1	22.1	40.7	DT	37.0	29.9	35.8	21.6	40.0	DT	36.8
7/6/1999	30.6	38.3	22.2	43.0	DT	46.0	30.5	37.4	22.3	42.2	DT	45.7	30.4	37.7	22.2	42.4	DT	45.8	30.6	37.2	21.6	41.4	DT	45.5
7/7/1999	26.7	33.3	8.9	31.7	DT	42.2	26.6	32.8	8.1	31.0	DT	42.0	26.6	32.9	9.1	31.4	DT	42.1	26.7	32.5	8.8	30.8	DT	41.9
7/8/1999	24.4	28.3	8.9	26.7	DM	32.1	24.3	28.1	9.0	26.5	DM	32.1	24.3	28.0	9.2	26.5	DM	32.1	24.3	28.0	9.5	26.5	DM	32.1
Total for event						185.8						184.6						185.1						184.2
7/23/1999	22.8	30.6	19.4	33.5	MT	-0.2	22.8	30.1	20.4	33.6	MT	-0.2	22.8	30.2	19.6	33.3	MT	-0.3	22.8	29.9	19.3	32.8	MT	-0.5
7/24/1999	23.9	35.0	15.6	35.9	DT	8.8	23.9	34.4	16.5	35.7	DT	8.8	23.9	34.7	15.6	35.6	DT	8.7	23.8	34.3	15.5	35.1	DT	8.6
7/25/1999	26.7	35.6	11.1	34.6	DT	16.7	26.7	35.1	11.2	34.2	DT	16.5	26.7	35.3	11.4	34.4	DT	16.6	26.7	34.9	12.3	34.4	DT	16.6
7/26/1999	25.6	32.8	16.1	33.9	DT	24.7	25.5	33.0	15.7	33.9	DT	24.7	25.5	32.8	16.2	33.9	DT	24.7	25.5	33.2	16.7	34.6	DT	24.9
7/27/1999	25.6	34.4	15.0	35.0	DT	33.3	25.6	34.1	15.9	35.2	DT	33.4	25.6	34.2	15.2	34.8	DT	33.3	25.6	34.0	15.9	35.0	DT	33.3
Total for event						83.3						83.2						82.9						82.9
7/13/1997	24.4	32.2	18.9	34.8	DT	9.4	24.4	31.9	19.7	35.0	DT	9.4	24.4	32.1	18.9	34.7	DT	9.3	24.4	32.3	18.8	34.9	DT	9.4
7/14/1997	26.1	33.3	20.0	36.6	MT+	18.2	26.0	32.9	19.8	36.0	MT+	18.0	26.1	33.1	20.0	36.4	MT+	18.1	26.0	33.1	19.8	36.2	MT+	18.1
7/15/1997	27.8	34.4	21.7	38.7	MT+	27.2	27.7	34.2	20.9	38.0	MT+	26.9	27.7	34.3	21.9	38.8	MT+	27.2	27.7	33.9	21.3	38.0	MT+	26.9
7/16/1997	22.2	30.6	23.9	36.5	MT+	34.7	22.1	30.3	23.4	35.9	MT	17.8	22.2	30.5	24.0	36.5	MT+	34.7	22.1	28.9	23.0	34.1	MT	17.2
7/17/1997	23.9	32.8	20.0	36.1	DT	42.8	23.9	32.5	20.3	36.0	DT	26.1	23.9	32.7	20.1	36.0	DT	42.8	23.8	31.4	19.1	34.1	DT	25.5
Total for event						132.3						98.3						132.2						97.2
7/28/1995	22.2	29.4	22.8	34.5	MT	16.4	22.2	28.9	23.2	34.4	MT	16.3	22.2	29.1	22.8	34.2	MT	16.3	22.2	28.6	22.5	33.6	MT	16.1
7/29/1995	27.2	33.3	22.2	38.0	MT+	25.8	27.1	32.4	21.8	36.8	MT+	25.4	27.2	32.7	22.2	37.4	MT+	25.6	27.2	32.1	21.6	36.4	MT+	25.3
7/30/1995	26.7	31.7	12.8	31.4	DT	31.9	26.6	31.1	12.9	30.8	DT	31.7	26.6	31.2	12.8	30.9	DT	31.7	26.6	31.3	12.6	30.9	DT	31.7
7/31/1995	24.4	32.2	15.6	33.1	DT	40.7	24.4	32.1	15.3	32.9	DM	23.9	24.4	31.4	15.0	32.0	DM	23.7	24.4	32.3	15.1	33.0	DM	24.0
Total for event						114.7						97.4						97.2						97.0

DM = Dry Moderate, DT = Dry Tropical, MT = Moist Tropical, MT+ = Moist Tropical Plus

FIGURE 3

BALTIMORE

	Control						Moderate Vegetation & Albedo Inc.						High Vegetation Increase						High Albedo Increase					
Date	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort
7/4/1999	23.3	35.0	22.2	39.7	MT+	1.7	23.3	34.3	22.1	38.8	MT+	1.6	23.3	34.4	22.3	39.1	MT+	1.7	23.3	34.2	22.0	38.7	MT+	1.6
7/5/1999	25.6	37.8	21.7	42.1	DT	2.5	25.5	37.1	21.6	41.4	MT+	2.4	25.5	37.2	21.8	41.6	MT+	2.4	25.6	37.0	21.6	41.3	MT+	2.4
7/6/1999	25.0	37.8	20.6	41.4	DT	2.9	24.9	37.1	20.4	40.7	DT	2.8	24.9	37.3	20.8	41.0	DT	2.9	25.0	37.1	20.1	40.4	DT	2.8
7/7/1999	26.1	34.4	13.9	34.5	DT	2.8	26.0	33.9	13.9	34.0	DT	2.7	25.9	33.9	14.1	34.1	DT	2.7	26.0	33.9	13.9	34.0	DT	2.7
7/8/1999	20.6	32.2	12.8	31.9	DM	2.0	20.5	32.0	13.5	31.9	DM	2.0	20.5	31.9	13.1	31.6	DM	1.9	20.6	31.9	14.0	32.1	DM	2.0
Total for event						*11.8*						*11.6*						*11.6*						*11.5*
7/23/1999	22.8	35.0	13.9	35.1	DT	0.9	22.8	34.5	14.0	34.6	DT	0.9	22.8	34.6	14.1	34.8	DT	0.9	22.8	34.2	13.9	34.3	DT	0.9
7/24/1999	25.0	30.6	18.3	32.9	MT	0.2	24.9	30.6	18.4	33.0	MT	0.2	24.9	30.3	18.3	32.7	MT	0.2	24.9	31.0	18.4	33.3	MT	0.2
7/25/1999	21.7	35.0	18.3	37.3	MT	0.6	21.5	34.9	18.6	37.3	MT	0.6	21.5	34.8	18.5	37.1	MT	0.6	21.4	35.0	18.5	37.3	MT	0.6
7/26/1999	22.2	32.2	16.1	33.3	MT	0.2	22.1	31.9	16.3	33.1	MT	0.2	22.1	31.9	16.2	33.1	MT	0.2	22.2	31.9	16.2	33.1	MT	0.2
7/27/1999	22.8	33.3	16.7	34.7	DT	0.8	22.8	32.6	16.7	34.1	DT	0.8	22.8	33.0	16.8	34.4	DT	0.8	22.8	32.3	16.4	33.6	DT	0.7
Total for event						*2.7*						*2.6*						*2.6*						*2.6*
7/13/1997	18.9	35	15.6	35.9	DT	1.2	18.9	34.5	15.2	35.1	DT	1.1	18.9	34.7	15.6	35.5	DT	1.2	18.9	34.3	15.7	35.2	DT	1.1
7/14/1997	21.1	35.6	17.8	37.6	DT	1.9	21.0	35.4	17.7	37.4	DT	1.9	21.0	35.3	17.8	37.3	DT	1.8	21.0	35.5	17.8	37.5	DM	0.8
7/15/1997	21.7	35	22.2	39.7	MT+	2.6	21.7	34.8	22.6	39.8	MT+	2.6	21.7	34.8	22.5	39.7	MT+	2.6	21.7	34.8	22.6	39.8	MT+	1.5
7/16/1997	23.3	35.6	17.8	37.6	DT	2.9	23.2	35.3	18.0	37.4	DT	2.9	23.2	35.4	17.9	37.5	DT	2.9	23.2	35.2	18.1	37.4	DT	1.8
Total for event						*8.6*						*8.5*						*8.5*						*5.3*
7/28/1995	23.9	32.8	22.2	37.5	MT+	3.2	23.9	32.3	22.1	37.0	MT	2.6	23.9	32.5	22.3	37.2	MT	2.7	23.9	32.1	21.9	36.6	MT	2.6
7/29/1995	26.1	34.4	22.8	39.5	MT+	3.4	26.0	33.1	22.4	37.9	MT+	3.2	26.0	33.6	22.8	38.7	MT+	3.3	26.0	32.4	21.8	36.9	MT+	3.1
7/30/1995	23.9	34.4	15.0	35.0	DT	2.9	23.8	33.5	15.0	34.1	DT	2.8	23.8	33.8	15.2	34.5	DT	2.9	23.8	33.0	14.6	33.4	DT	2.8
Total for event						*9.5*						*8.7*						*8.8*						*8.5*

DM = Dry Moderate, DT = Dry Tropical, MT = Moist Tropical, MT+ = Moist Tropical Plus

FIGURE 4

HOUSTON

	Control						Moderate Vegetation & Albedo Inc.						High Vegetation Increase						High Albedo Increase					
Date	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort
6/16/1998	23.3	35.6	25.0	42.3	MT+	0.5	23.3	35.0	24.8	41.6	MT+	0.5	23.3	35.4	25.4	42.5	MT+	0.5	23.3	35.3	25.2	42.2	MT+	0.5
6/17/1998	26.7	33.3	22.2	38.0	MT+	0.2	26.7	33.2	22.6	38.1	MT+	0.2	26.6	33.1	22.3	37.8	MT+	0.2	26.7	33.2	22.5	38.1	MT+	0.2
6/18/1998	27.2	36.1	23.9	42.0	MT+	0.4	27.2	35.8	23.8	41.6	MT+	0.4	27.1	35.8	23.6	41.4	MT+	0.3	27.2	36.0	24.0	41.9	MT+	0.4
6/19/1998	27.8	36.1	20.6	39.7	MT+	0.0	27.7	35.6	20.4	39.1	MT+	0.0	27.7	35.9	20.9	39.7	MT+	0.1	27.8	35.6	20.4	39.2	MT+	0.0
6/20/1998	26.1	36.1	20.6	39.7	MT+	0.0	26.1	35.6	20.5	39.1	MT+	0.0	26.1	35.9	20.5	39.4	MT+	0.0	26.1	35.3	20.3	38.7	MT+	0.0
6/21/1998	25.6	36.7	19.4	39.6	MT+	0.0	25.5	36.2	19.4	39.1	MT+	0.0	25.5	36.5	19.4	39.4	MT+	0.0	25.6	35.9	19.2	38.7	MT+	0.0
Total for event						*1.1*						*1.1*						*1.2*						*1.1*
7/18/2000	26.1	36.1	20.0	39.4	DT	0.0	26.1	35.5	19.8	38.7	MT+	0.0	26.1	35.9	20.0	39.1	MT+	0.0	26.1	35.2	19.5	38.2	MT+	0.0
7/19/2000	26.1	37.8	16.7	39.2	DT	0.0	26.0	37.1	16.4	38.3	DT	0.0	26.0	37.7	16.8	39.1	DT	0.0	26.1	36.7	15.7	37.6	DT	0.0
7/20/2000	25.6	38.9	15.0	39.5	DT	0.0	25.6	37.9	14.1	38.0	DT	0.0	25.5	38.6	14.9	39.1	DT	0.0	25.6	37.8	14.4	38.1	DT	0.0
7/21/2000	25.6	37.2	15.6	38.0	DT	0.0	25.6	36.4	14.3	36.6	DT	0.0	25.5	37.0	15.6	37.8	DT	0.0	25.6	35.9	13.7	36.0	DT	0.0
7/22/2000	25.6	36.7	17.8	38.7	DT	0.0	25.5	36.0	17.4	37.7	DT	0.0	25.5	37.3	17.8	39.2	DT	0.0	25.5	36.1	17.5	37.9	DT	0.0
Total for event						*0.0*						*0.0*						*0.0*						*0.0*
5/31/1998	23.9	35.6	21.1	39.5	MT+	0.1	23.9	35.2	21.1	39.1	MT+	0.1	23.9	35.4	21.3	39.5	MT+	0.1	23.9	35.1	21.1	39.0	MT+	0.1
6/1/1998	21.1	35.6	18.9	38.2	DT	0.0	21.0	34.8	18.4	37.1	DT	0.0	21.0	35.4	19.0	38.1	DT	0.0	21.0	35.0	18.4	37.3	DT	0.0
6/2/1998	23.9	36.1	20.6	39.7	MT+	0.0	23.9	35.5	20.5	39.0	MT+	0.0	23.8	36.0	20.4	39.5	MT+	0.0	23.9	35.3	20.3	38.7	MT+	0.0
Total for event						*0.1*						*0.1*						*0.1*						*0.1*
5/13/1995	26.1	31.7	25.0	38.4	MT+	0.5	26.1	31.5	25.3	38.5	MT+	0.5	26.1	31.8	24.9	38.4	MT+	0.5	26.1	31.8	25.0	38.5	MT+	0.5
5/14/1995	26.7	32.8	25.0	39.5	MT+	0.5	26.7	30.7	24.2	36.9	MT+	0.4	26.7	32.2	25.2	39.1	MT+	0.5	26.8	30.8	25.2	37.7	MT+	0.5
5/15/1995	26.1	32.2	22.8	37.3	MT+	0.3	26.0	27.2	21.7	31.6	MT+	0.1	26.0	26.4	20.3	29.9	MT+	0.0	26.0	31.2	22.1	35.9	MT+	0.2
5/16/1995	26.1	33.3	19.5	36.3	MT+	0.0	25.8	34.0	19.3	36.8	MT+	0.0	25.7	32.5	19.0	35.1	MT+	0.0	25.9	33.2	20.1	36.5	MT+	0.0
Total for event						*1.3*						*1.1*						*1.0*						*1.2*

DM = Dry Moderate, DT = Dry Tropical, MT = Moist Tropical, MT+ = Moist Tropical Plus

FIGURE 5

CHICAGO

	Control						Moderate Vegetation & Albedo Inc.						High Vegetation Increase						High Albedo Increase					
Date	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort	T5	T17	Td17	AT17	AM	Mort
7/13/1995	27.2	39.4	23.3	44.8	MT+	70.9	27.2	39.1	23.7	44.8	MT+	70.8	27.2	38.9	23.5	44.4	MT+	70.3	27.2	39.2	23.8	45.0	MT+	71.1
7/14/1995	28.3	37.8	24.4	44.0	MT+	72.9	28.3	37.7	24.9	44.3	MT+	73.3	28.2	37.3	24.5	43.7	MT+	72.4	28.3	37.9	25.0	44.6	MT+	73.7
7/15/1995	27.8	35.0	21.7	39.3	MT+	69.3	27.7	34.7	21.6	39.0	MT+	68.8	27.7	34.8	21.1	38.7	MT+	68.4	27.8	34.9	21.7	39.2	MT+	69.1
7/16/1995	24.4	31.7	21.1	35.7	MT+	67.2	24.3	31.5	21.6	35.8	MT+	67.4	24.3	31.2	22.1	35.8	MT+	67.4	24.3	31.9	22.6	36.8	MT+	68.9
Total for event						280.2						280.3						278.5						282.8
6/6/1999	25.0	32.8	20.6	36.4	MT+	58.7	25.0	32.6	21.0	36.6	MT+	58.9	25.0	33.2	21.6	37.4	MT+	60.2	25.0	32.9	21.0	36.8	MT+	59.2
6/7/1999	25.0	31.1	15.6	32.0	MT+	55.4	25.0	30.7	15.6	31.6	MT+	54.9	24.9	30.7	16.4	31.9	MT+	55.4	25.0	30.8	15.8	31.8	MT+	55.1
6/8/1999	21.7	32.2	17.2	33.9	DT	57.0	21.6	31.5	17.0	33.1	MT+	60.2	21.6	31.8	17.1	33.4	MT+	60.7	21.6	30.8	17.1	32.4	MT+	59.3
6/9/1999	21.7	30.6	16.1	31.7	MT+	61.4	21.6	29.7	15.5	30.5	MT	49.0	21.6	30.3	16.4	31.6	MT+	61.2	21.6	29.6	15.6	30.5	MT	48.9
6/10/1999	21.1	30.6	17.2	32.3	MT+	62.3	21.0	30.4	17.8	32.4	MT+	59.2	21.0	30.3	17.9	32.3	MT+	62.3	21.0	30.1	17.9	32.1	MT+	58.8
Total for event						294.9						282.1						299.8						281.3
8/6/2001	22.8	33.3	17.8	35.3	MT	46.3	22.8	32.8	17.7	34.7	MT	45.5	22.8	33.0	17.6	34.9	MT	45.7	22.8	32.8	17.5	34.6	MT	45.3
8/7/2001	23.9	34.4	23.9	40.3	MT+	61.1	23.8	34.0	23.3	39.5	MT+	60.0	23.8	34.0	24.0	39.9	MT+	60.6	23.9	34.2	23.5	39.8	MT+	60.4
8/8/2001	25.6	33.3	18.9	35.9	MT+	58.0	25.5	32.7	18.3	35.0	MT+	56.7	25.5	33.0	19.5	36.0	MT+	58.0	25.5	32.5	18.0	34.6	MT+	56.1
8/9/2001	25.0	34.4	20.6	38.0	MT+	64.2	24.9	34.8	21.5	39.0	MT+	65.7	24.9	34.1	20.7	37.8	MT+	63.9	24.9	35.3	22.1	39.9	MT+	66.9
Total for event						229.6						227.8						228.2						228.7
7/4/1988	14.4	31.1	8.9	29.5	DT	41.0	14.4	30.7	9.2	29.2	DM	37.4	14.4	30.7	9.1	29.1	DM	37.3	14.4	30.8	9.0	29.2	DM	37.4
7/5/1988	16.7	36.7	13.9	36.8	DT	54.8	16.7	36.4	14.1	36.5	DT	51.3	16.7	36.3	14.1	36.4	DT	51.1	16.7	36.4	14.2	36.6	DT	51.4
7/6/1988	19.4	35.6	16.1	36.7	DT	57.9	19.4	35.3	16.3	36.5	DT	54.4	19.4	35.1	16.0	36.1	DT	53.9	19.4	35.2	16.4	36.5	DT	54.4
7/7/1988	24.4	35.6	15.6	36.5	DT	60.7	24.3	35.2	15.7	36.1	DT	57.0	24.3	35.1	15.5	35.9	DT	56.7	24.3	35.0	15.6	35.9	DT	56.7
7/8/1988	22.2	35.0	15.0	35.6	DT	62.6	22.1	34.3	14.8	34.8	DT	58.3	22.1	34.4	15.0	35.0	DT	58.6	22.1	34.2	14.5	34.5	DT	57.9
Total for event						277.1						258.5						257.7						257.9
DM=Dry Moderate, DT=Dry Tropical, MT=Moist Tropical, MT+=Moist Tropical Plus																								

For Chicago, all three heat waves that were used for Detroit in the earlier analysis were retained (Figure 5). As is well-known, the July, 1995 event has an approximately 100 year occurrence interval, and the 1988 heat wave, which was also rather extreme, has a return period of 10-20 years. The other two evaluated events are rather typical.

The New York and Baltimore heat waves were general mixtures of MT+ and DT days. For New York, the early and late July, 1999 events were mostly drier DT, with very high temperatures but with dewpoints that remained in the lower and mid teens C (about 52-58 degrees F), and even lower toward the end of the early July event. The other two events, during the July of 1995 and 1997, were slightly cooler but generally more humid, with dewpoints mostly above 20 degrees C (68 degrees F). These heat waves were a bit more humid in general for Baltimore. The Houston events were mostly dominated by very oppressive MT+ days, which are both hot and humid. We included one very hot (temperatures up to 39 degrees C or 102 degrees F) and dry heat wave from July, 2000. Temperatures above 100 degrees are very rare for Houston because of its proximity to humid air mass sources which generally remain in the 90s. The Chicago events include the very deadly heat wave of 1995 that killed hundreds of people (Klinenberg, 2002). On July 13, 1995, temperatures approached 40 degrees C (104 degrees F), making it one of the hottest days in Chicago history. During that heat wave, dewpoints were in the low to mid 20s C (low 70s F), and the combination of record heat and high dewpoints was particularly deadly. We also included the hot, dry heat wave of 1988 for comparative purposes.

For this report, as a new feature we have included “delta figures”, which identify differences between the actual meteorological and mortality data and the modeled results (Figures 6-9). For all four cities, reductions in temperature and dewpoint are relatively modest, usually averaging less than 1 degree C. In some cases, the modifications actually led to dewpoint increases. However, past research has indicated that just a small decrease in temperature, dewpoint, and associated apparent temperature can possibly mean the difference between life and death.

The thermal changes for New York and Baltimore are somewhat similar to what we found for Philadelphia in our previous study. Generally, the largest temperature drops occur within the high albedo scenarios, and the smallest differentials are associated with the high vegetation scenarios. In addition, greater temperature drops occur during the afternoon rather than the morning. For example, looking at the deltas for New York City under the high albedo scenario (Figure 6), 5PM temperature reductions of over 1 degree C are noted for four of the 19 heat wave days analyzed; 11 of the days have drops of 0.7 degree C (1 degree F) or greater. On July 16, 1997, there is a reduction of 1.7 degrees C (about 3 degrees F). This contrasts with morning reductions, which never exceed 0.1 degree C for any day within the high albedo scenario. This morning-afternoon differential response occurs within the high vegetation and increased albedo/vegetation scenarios as well. For the high vegetation scenarios, the deltas are at a minimum, and no day within the 19 heat wave days has an afternoon temperature reduction exceeding 1 degree C. The increased albedo/vegetation scenarios are somewhat midway between the high albedo and the high vegetation. Baltimore's thermal responses are almost identical to New York's.

FIGURE 6

NEW YORK CITY

	Control					Moderate Vegetation & Albedo Inc.					High Vegetation Increase					High Albedo Increase				
Date	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort
7/4/1999	27.8	33.9	23.3	39.3	28.3	0.0	-0.6	-0.2	-0.8	-0.3	0.0	-0.5	0.0	-0.5	-0.2	0.0	-0.9	-0.5	-1.2	-0.4
7/5/1999	30.0	36.7	22.2	41.4	37.2	-0.1	-0.8	-0.7	-1.3	-0.4	-0.1	-0.6	-0.1	-0.6	-0.2	-0.1	-0.9	-0.6	-1.3	-0.4
7/6/1999	30.6	38.3	22.2	43.0	46.0	-0.1	-0.9	0.1	-0.8	-0.3	-0.2	-0.6	0.0	-0.6	-0.2	0.0	-1.1	-0.6	-1.5	-0.5
7/7/1999	26.7	33.3	8.9	31.7	42.2	-0.1	-0.5	-0.8	-0.7	-0.2	-0.1	-0.4	0.2	-0.3	-0.1	0.0	-0.8	-0.1	-0.8	-0.3
7/8/1999	24.4	28.3	8.9	26.7	32.1	-0.1	-0.2	0.1	-0.2	-0.1	-0.1	-0.3	0.3	-0.2	-0.1	-0.1	-0.3	0.6	-0.2	-0.1
Total for event					*185.8*					*-1.3*					*-0.7*					*-1.7*
7/23/1999	22.8	30.6	19.4	33.5	-0.2	0.0	-0.5	1.0	0.1	0.0	0.0	-0.4	0.2	-0.3	-0.1	0.0	-0.7	-0.1	-0.8	-0.2
7/24/1999	23.9	35.0	15.6	35.9	8.8	0.0	-0.6	0.9	-0.1	0.0	0.0	-0.3	0.0	-0.3	-0.1	-0.1	-0.7	-0.1	-0.7	-0.2
7/25/1999	26.7	35.6	11.1	34.6	16.7	0.0	-0.5	0.1	-0.4	-0.1	0.0	-0.4	0.3	-0.2	-0.1	0.0	-0.7	1.2	-0.2	-0.1
7/26/1999	25.6	32.8	16.1	33.9	24.7	-0.1	0.2	-0.4	0.0	0.0	-0.1	0.0	0.1	0.0	0.0	-0.1	0.4	0.6	0.7	0.2
7/27/1999	25.6	34.4	15.0	35.0	33.3	0.0	-0.3	0.9	0.2	0.1	0.0	-0.2	0.2	-0.1	0.0	0.0	-0.4	0.9	0.1	0.0
Total for event					*83.3*					*-0.1*					*-0.3*					*-0.3*
7/13/1997	24.4	32.2	18.9	34.8	9.4	0.0	-0.3	0.8	0.2	0.1	0.0	-0.1	0.0	-0.1	0.0	0.0	0.1	-0.1	0.1	0.0
7/14/1997	26.1	33.3	20.0	36.6	18.2	-0.1	-0.4	-0.2	-0.6	-0.2	0.0	-0.2	0.0	-0.2	-0.1	-0.1	-0.2	-0.2	-0.4	-0.1
7/15/1997	27.8	34.4	21.7	38.7	27.2	-0.1	-0.2	-0.8	-0.7	-0.2	-0.1	-0.1	0.2	0.0	0.0	-0.1	-0.5	-0.4	-0.8	-0.3
7/16/1997	22.2	30.6	23.9	36.5	34.7	-0.1	-0.3	-0.5	-0.6	-16.9	0.0	-0.1	0.1	0.0	0.0	-0.1	-1.7	-0.9	-2.4	-17.5
7/17/1997	23.9	32.8	20.0	36.1	42.8	0.0	-0.3	0.3	-0.1	-16.7	0.0	-0.1	0.1	0.0	0.0	-0.1	-1.4	-0.9	-2.0	-17.3
Total for event					*132.3*					*-34.0*					*-0.1*					*-35.2*
7/28/1995	22.2	29.4	22.8	34.5	16.4	0.0	-0.5	0.4	-0.2	-0.1	0.0	-0.3	0.0	-0.3	-0.1	0.0	-0.8	-0.3	-1.0	-0.3
7/29/1995	27.2	33.3	22.2	38.0	25.8	-0.1	-0.9	-0.4	-1.2	-0.4	0.0	-0.6	0.0	-0.6	-0.2	0.0	-1.2	-0.6	-1.6	-0.5
7/30/1995	26.7	31.7	12.8	31.4	31.9	-0.1	-0.6	0.1	-0.5	-0.2	-0.1	-0.5	0.0	-0.5	-0.2	-0.1	-0.4	-0.2	-0.5	-0.2
7/31/1995	24.4	32.2	15.6	33.1	40.7	0.0	-0.1	-0.3	-0.2	-16.8	0.0	-0.8	-0.6	-1.1	-17.0	0.0	0.1	-0.5	-0.1	-16.7
Total for event					*114.7*					*-17.4*					*-17.5*					*-17.7*

FIGURE 7

BALTIMORE

	Control					Moderate Vegetation & Albedo Inc.					High Vegetation Increase					High Albedo Increase				
Date	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort
7/4/1999	23.3	35.0	22.2	39.7	1.7	0.0	-0.7	-0.1	-0.8	-0.1	0.0	-0.6	0.1	-0.5	-0.1	0.0	-0.8	-0.2	-1.0	-0.1
7/5/1999	25.6	37.8	21.7	42.1	2.5	-0.1	-0.7	-0.1	-0.7	-0.1	-0.1	-0.6	0.1	-0.5	0.0	0.0	-0.8	-0.1	-0.8	-0.1
7/6/1999	25.0	37.8	20.6	41.4	2.9	-0.1	-0.7	-0.2	-0.8	-0.1	-0.1	-0.5	0.2	-0.4	0.0	0.0	-0.7	-0.5	-1.0	-0.1
7/7/1999	26.1	34.4	13.9	34.5	2.8	-0.1	-0.5	0.0	-0.5	-0.1	-0.2	-0.5	0.2	-0.4	0.0	-0.1	-0.5	0.0	-0.5	-0.1
7/8/1999	20.6	32.2	12.8	31.9	2.0	-0.1	-0.2	0.7	0.0	0.0	-0.1	-0.3	0.3	-0.2	0.0	0.0	-0.3	1.2	0.2	0.0
Total for event					*11.8*					*-0.3*					*-0.2*					*-0.3*
7/23/1999	22.8	35.0	13.9	35.1	0.9	0.0	-0.5	0.1	-0.5	0.0	0.0	-0.4	0.2	-0.3	0.0	0.0	-0.8	0.0	-0.8	-0.1
7/24/1999	25.0	30.6	18.3	32.9	0.2	-0.1	0.0	0.1	0.1	0.0	-0.1	-0.3	0.0	-0.2	0.0	-0.1	0.4	0.1	0.4	0.0
7/25/1999	21.7	35.0	18.3	37.3	0.6	-0.2	-0.1	0.3	0.1	0.0	-0.2	-0.2	0.2	-0.1	0.0	-0.3	0.0	0.2	0.0	0.0
7/26/1999	22.2	32.2	16.1	33.3	0.2	-0.1	-0.3	0.2	-0.2	0.0	-0.1	-0.3	0.1	-0.2	0.0	0.0	-0.3	0.1	-0.3	0.0
7/27/1999	22.8	33.3	16.7	34.7	0.8	0.0	-0.7	0.0	-0.6	-0.1	0.0	-0.3	0.1	-0.3	0.0	0.0	-1.0	-0.3	-1.1	-0.1
Total for event					*2.7*					*-0.1*					*-0.1*					*-0.2*
7/13/1997	18.9	35.0	15.6	35.9	1.2	0.0	-0.5	-0.4	-0.7	-0.1	0.0	-0.3	0.0	-0.4	0.0	0.0	-0.7	0.1	-0.7	-0.1
7/14/1997	21.1	35.6	17.8	37.6	1.9	-0.1	-0.2	-0.1	-0.2	0.0	-0.1	-0.3	0.0	-0.3	0.0	-0.1	-0.1	0.0	-0.1	-1.1
7/15/1997	21.7	35.0	22.2	39.7	2.6	0.0	-0.2	0.4	0.1	0.0	0.0	-0.2	0.3	0.0	0.0	0.0	-0.2	0.4	0.1	-1.1
7/16/1997	23.3	35.6	17.8	37.6	2.9	-0.1	-0.3	0.2	-0.1	0.0	-0.1	-0.2	0.1	-0.1	0.0	-0.1	-0.4	0.3	-0.2	-1.1
Total for event					*8.6*					*-0.1*					*-0.1*					*-3.3*
7/28/1995	23.9	32.8	22.2	37.5	3.2	0.0	-0.5	-0.1	-0.5	-0.6	0.0	-0.3	0.1	-0.2	-0.6	0.0	-0.7	-0.3	-0.9	-0.6
7/29/1995	26.1	34.4	22.8	39.5	3.4	-0.1	-1.3	-0.4	-1.6	-0.2	-0.1	-0.8	0.0	-0.7	-0.1	-0.1	-2.0	-1.0	-2.6	-0.3
7/30/1995	23.9	34.4	15.0	35.0	2.9	-0.1	-0.9	0.0	-0.9	-0.1	-0.1	-0.6	0.2	-0.5	0.0	-0.1	-1.4	-0.4	-1.6	-0.1
Total for event					*9.5*					*-0.8*					*-0.7*					*-1.0*

FIGURE 8

HOUSTON

	Control					Moderate Vegetation & Albedo Inc.					High Vegetation Increase					High Albedo Increase				
Date	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort
6/16/1998	23.3	35.6	25.0	42.3	0.5	0.0	-0.6	-0.2	-0.7	0.0	0.0	-0.2	0.4	0.2	0.0	0.0	-0.3	0.2	-0.1	0.0
6/17/1998	26.7	33.3	22.2	38.0	0.2	0.0	-0.1	0.4	0.1	0.0	-0.1	-0.2	0.1	-0.2	0.0	0.0	-0.1	0.3	0.1	0.0
6/18/1998	27.2	36.1	23.9	42.0	0.4	0.0	-0.3	-0.1	-0.4	0.0	-0.1	-0.3	-0.3	-0.5	0.0	0.0	-0.1	0.1	-0.1	0.0
6/19/1998	27.8	36.1	20.6	39.7	0.0	-0.1	-0.5	-0.2	-0.6	0.0	-0.1	-0.2	0.3	0.0	0.0	0.0	-0.5	-0.2	-0.6	0.0
6/20/1998	26.1	36.1	20.6	39.7	0.0	0.0	-0.5	-0.1	-0.6	0.0	0.0	-0.2	-0.1	-0.3	0.0	0.0	-0.8	-0.3	-1.0	0.0
6/21/1998	25.6	36.7	19.4	39.6	0.0	-0.1	-0.5	0.0	-0.5	0.0	-0.1	-0.2	0.0	-0.2	0.0	0.0	-0.8	-0.2	-0.9	0.0
Total for event					*1.1*					*0.0*					*0.0*					*0.0*
7/18/2000	26.1	36.1	20.0	39.4	0.0	0.0	-0.6	-0.2	-0.7	0.0	0.0	-0.2	0.0	-0.2	0.0	0.0	-0.9	-0.5	-1.1	0.0
7/19/2000	26.1	37.8	16.7	39.2	0.0	-0.1	-0.7	-0.3	-0.9	0.0	-0.1	-0.1	0.1	-0.1	0.0	0.0	-1.2	-1.0	-1.6	0.0
7/20/2000	25.6	38.9	15.0	39.5	0.0	0.0	-1.0	-0.9	-1.4	0.0	-0.1	-0.3	-0.1	-0.4	0.0	0.0	-1.1	-0.6	-1.4	0.0
7/21/2000	25.6	37.2	15.6	38.0	0.0	0.0	-0.8	-1.3	-1.4	0.0	-0.1	-0.2	0.0	-0.2	0.0	0.0	-1.3	-1.9	-2.1	0.0
7/22/2000	25.6	36.7	17.8	38.7	0.0	-0.1	-0.7	-0.4	-0.9	0.0	-0.1	0.6	0.0	0.6	0.0	-0.1	-0.6	-0.3	-0.8	0.0
Total for event					*0.0*					*0.0*					*0.0*					*0.0*
5/31/1998	23.9	35.6	21.1	39.5	0.1	0.0	-0.4	0.0	-0.4	0.0	0.0	-0.2	0.2	-0.1	0.0	0.0	-0.5	0.0	-0.5	0.0
6/1/1998	21.1	35.6	18.9	38.2	0.0	-0.1	-0.8	-0.5	-1.1	0.0	-0.1	-0.2	0.1	-0.1	0.0	-0.1	-0.6	-0.5	-0.9	0.0
6/2/1998	23.9	36.1	20.6	39.7	0.0	0.0	-0.6	-0.1	-0.7	0.0	-0.1	-0.1	-0.2	-0.2	0.0	0.0	-0.8	-0.3	-1.0	0.0
Total for event					*0.1*					*0.0*					*0.0*					*0.0*
5/13/1995	26.1	31.7	25.0	38.4	0.5	0.0	-0.2	0.3	0.1	0.0	0.0	0.1	-0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0
5/14/1995	26.7	32.8	25.0	39.5	0.5	0.0	-2.1	-0.8	-2.6	-0.1	0.0	-0.6	0.2	-0.4	0.0	0.1	-2.0	0.2	-1.8	0.0
5/15/1995	26.1	32.2	22.8	37.3	0.3	-0.1	-5.0	-1.1	-5.7	-0.1	-0.1	-5.8	-2.5	-7.4	-0.3	-0.1	-1.0	-0.7	-1.4	-0.1
5/16/1995	26.1	33.3	19.5	36.3	0.0	-0.3	0.7	-0.2	0.6	0.0	-0.4	-0.8	-0.5	-1.1	0.0	-0.2	-0.1	0.6	0.3	0.0
Total for event					*1.3*					*-0.2*					*-0.3*					*-0.1*

FIGURE 9

CHICAGO

	Control					Moderate Vegetation & Albedo Inc.					High Vegetation Increase					High Albedo Increase				
Date	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort	T5	T17	Td17	AT17	Mort
7/13/1995	27.2	39.4	23.3	44.8	70.9	0.0	-0.3	0.4	-0.1	-0.1	0.0	-0.5	0.2	-0.4	-0.6	0.0	-0.8	0.7	-0.3	0.2
7/14/1995	28.3	37.8	24.4	44.0	72.9	0.0	-0.1	0.5	0.3	0.4	-0.1	-0.5	0.1	-0.4	-0.5	0.0	-0.2	1.0	0.6	0.8
7/15/1995	27.8	35.0	21.7	39.3	69.3	-0.1	-0.3	-0.1	-0.3	-0.5	-0.1	-0.2	-0.6	-0.6	-0.9	0.0	-0.4	0.0	-0.4	-0.2
7/16/1995	24.4	31.7	21.1	35.7	67.2	-0.1	-0.2	0.5	0.2	0.2	-0.1	-0.5	1.0	0.2	0.2	-0.2	0.2	3.1	2.3	1.7
Total for event					*280.2*					*0.0*					*-1.8*					*2.6*
6/6/1999	25.0	32.8	20.6	36.4	58.7	0.0	-0.2	0.4	0.1	0.2	0.0	0.4	1.0	1.0	1.4	0.0	0.2	1.1	0.9	0.5
6/7/1999	25.0	31.1	15.6	32.0	55.4	0.0	-0.4	0.0	-0.4	-0.6	-0.1	-0.4	0.8	0.0	-0.1	0.0	0.1	1.4	0.8	-0.3
6/8/1999	21.7	32.2	17.2	33.9	57.0	-0.1	-0.7	-0.2	-0.8	3.2	-0.1	-0.4	-0.1	-0.5	3.7	-0.2	-2.3	0.7	-1.9	2.3
6/9/1999	21.7	30.6	16.1	31.7	61.4	-0.1	-0.9	-0.6	-1.2	-12.5	-0.1	-0.3	0.3	-0.2	-0.3	-0.2	-0.9	0.2	-0.8	-12.5
6/10/1999	21.1	30.6	17.2	32.3	62.3	-0.1	-0.2	0.6	0.1	-3.1	-0.1	-0.3	0.7	0.1	0.1	-0.2	-0.9	1.5	0.0	-3.4
Total for event					*294.9*					*-12.8*					*4.9*					*-13.5*
8/6/2001	22.8	33.3	17.8	35.3	46.3	0.0	-0.5	-0.1	-0.6	-0.8	0.0	-0.3	-0.2	-0.4	-0.6	0.0	-0.8	-0.1	-0.9	-1.0
8/7/2001	23.9	34.4	23.9	40.3	61.1	-0.1	-0.4	-0.6	-0.8	-1.2	-0.1	-0.4	0.1	-0.3	-0.5	0.0	-0.8	-1.0	-1.6	-0.8
8/8/2001	25.6	33.3	18.9	35.9	58.0	-0.1	-0.6	-0.6	-0.9	-1.3	-0.1	-0.3	0.6	0.0	0.1	-0.2	-1.1	-0.6	-1.4	-1.8
8/9/2001	25.0	34.4	20.6	38.0	64.2	-0.1	0.4	0.9	1.0	1.5	-0.1	-0.3	0.1	-0.2	-0.4	-0.2	1.6	3.0	3.6	2.7
Total for event					*229.6*					*-1.8*					*-1.4*					*-0.9*
7/4/1988	14.4	31.1	8.9	29.5	41.0	0.0	-0.4	0.3	-0.3	-3.6	0.0	-0.4	0.2	-0.4	-3.7	0.0	-1.0	0.1	-1.0	-3.6
7/5/1988	16.7	36.7	13.9	36.8	54.8	0.0	-0.3	0.2	-0.3	-3.5	0.0	-0.4	0.2	-0.4	-3.7	0.0	-0.8	0.5	-0.6	-3.4
7/6/1988	19.4	35.6	16.1	36.7	57.9	0.0	-0.3	0.2	-0.2	-3.5	0.0	-0.5	-0.1	-0.6	-4.0	0.0	-0.8	0.5	-0.5	-3.5
7/7/1988	24.4	35.6	15.6	36.5	60.7	-0.1	-0.4	0.1	-0.4	-3.7	-0.1	-0.5	-0.1	-0.6	-4.0	-0.2	-1.1	0.0	-1.1	-4.0
7/8/1988	22.2	35.0	15.0	35.6	62.6	-0.1	-0.7	-0.2	-0.8	-4.3	-0.1	-0.6	0.0	-0.6	-4.0	-0.2	-1.3	-0.3	-1.5	-4.7
Total for event					*277.1*					*-18.7*					*-19.4*					*-19.2*

Deltas for Houston and Chicago (Figures 8 and 9) show similarities to those found in Baltimore and New York. For both cities, the largest temperature drops occur at 5PM within the high albedo scenarios, and the smallest are found at 5AM in the high vegetation scenarios. For both cities within the high albedo scenario, several of the heat wave days exhibit afternoon temperature reductions exceeding 1 degree C (1.6 degrees F). The lack of a morning temperature response in both cities for all the scenarios is striking, but not all that surprising. It is intuitive to think that high albedo surfaces will have a greater impact during the sunny part of the day than during the night. Additionally, increasing albedo seems to be more effective than increasing vegetation in reducing afternoon temperatures.

The data suggest that increasing surface albedo is much more effective in reducing afternoon temperatures than increasing vegetation. In addition, none of the modified scenarios seem to have a great impact on morning temperatures.

Dewpoint responses are somewhat different for New York and Baltimore (Figures 6 and 7). For a majority of the days in the high vegetation scenario, there are very small increases in afternoon dewpoint temperature, something that we noted in the original study. For most of the high albedo heat wave days, there are slight afternoon dewpoint decreases, but they are generally smaller than the afternoon temperature decreases. Thus, afternoon apparent temperature (AT) reductions are considerably larger for the high albedo scenarios than the high vegetation. A few of the AT values actually diminish by more than 2 degrees C in both cities under the case 20 scenarios. This should, and does, have an impact on the mortality response among the scenarios, with the high albedo being much more effective than the high vegetation.

For Houston and Chicago (Figures 8 and 9), 5PM dewpoint responses are generally smaller than 5PM temperature responses, regardless of scenario. In the Houston case, most dewpoint reductions are only a few tenths of a degree C, and there are a few dewpoint increases, particularly when the air mass is MT+. The largest dewpoint drops occur during the very hot DT heat wave of July, 2000, especially in the high albedo scenario. In Chicago, there are more dewpoint increases, and many of these unfortunately occur during the modeling of the 1995 mega-heat wave. Surprisingly, some of the largest dewpoint increases are noted in the high albedo scenario. Thus, the apparent temperature deltas during the 1995 heat wave are not encouraging and suggest little benefit from surface modification. However, for the other Chicago heat waves, there is a small apparent temperature reduction for all scenarios, and some days have negative deltas exceeding 1 degree C, especially within the high albedo scenario. This suggests that surface modifications appear to be most beneficial during the more typical Chicago heat wave, but seem less effective during the very extreme event of 1995.

Results: Mortality Changes

Mean daily mortality for offensive air mass days during the heat waves (assuming no heat island reduction initiatives are in place) are well above the summer baseline for New York City and Chicago, and slightly above the baseline for Baltimore (Table 5). For Houston, there is no discernible impact of heat on mortality, even during the offensive air mass days. This is not surprising, considering the low variability summer climate of Houston, which is consistently very warm. However, New Orleans showed a small mortality response during the offensive air mass days in our previous study (Kalkstein and Sheridan, 2003), so the lack of any response in Houston is a bit unique among U.S. cities. Thus, any modifications to the urban environment in Houston, while important for quality-of-life reasons, will have little impact upon heat-related mortality.

TABLE 5.
Mean Daily Mortality Above Baseline Values for Offensive Synoptic Categories

CITY	AIR MASS TYPE	EXCESS MORTALITY
Baltimore	DT	2.0
	MT+	2.8
Chicago	DT	6.8
	MT+	11.5
Houston	DT	0
	MT+	0
New York	DT	17.1
	MT+	18.8

Initial results when instituting the MM5 models suggest that a sharp decrease in mortality occurred if a day “jumped” from an offensive air mass to a non-offensive one, since no anomalous mortality would be calculated for the non-offensive day. To remedy this situation, a separate mortality regression equation was also calculated for non-offensive days that bordered on the offensive. This presented a more realistic expression of heat-related mortality for hot, non-offensive air mass days that sometimes occur within a heat wave.

The magnitude of mortality reductions that occurred during the heat waves in the different cities was variable. The best results were obtained in New York and Chicago, where some significant reductions were obtained (Figures 6 and 9), and mortality declines sometimes exceeding 20 percent during individual heat waves were observed. Of the four cities evaluated, New York’s results were most impressive when evaluating percentage declines under the varying modifications. During the heat waves of July, 1995 and July, 1997, there were two days that actually switched air mass type (one in each air mass) from offensive to non-offensive (Figure 2). This led to significant decreases in mortality on these particular days – July 16, 1997 and July 31, 1995. In addition, on July 17, 1997, the temperature cooled significantly enough to lead to reduced mortality even though an air mass change did not occur.

The results for New York paralleled those found for Philadelphia in the original study in that most of the mortality reductions occurred on a few of the days with air mass changes (mortality can also be reduced even if an air mass change doesn't occur; the mortality algorithm is rerun for the updated meteorological data within each scenario and different mortality numbers can be the result). In addition, it is clear that higher albedo is more effective in lowering mortality in New York than increasing vegetation cover. The delta chart for New York (Figure 6) shows generally higher mortality drops for high albedo than for high vegetation scenarios. The only exception here is for July 31, 1995, where significant reductions occurred for all three cases because the temperature drop was significant enough to create an air mass change for the three scenarios.

The mortality drops for the July, 1997 heat wave in New York exceed 20 percent, the best result obtained from all four cities. Two of the five heat wave days showed significant mortality reductions within the increased albedo scenarios. For that heat wave, the increased vegetation scenario was noteworthy because of the lack of any meteorological or mortality response.

The heat wave analysis for Chicago was somewhat surprising because total mortality during these extreme events actually exceeded totals that were achieved during heat waves in New York (Figure 5). This is in spite of the fact that the population of the Chicago SMSA is roughly half that of New York, and clearly Chicago is a very sensitive city when it comes to extreme heat. Another reason for the high Chicago mortality numbers relates to the strength of the heat/mortality relationship in this city, which is higher than any of the four cities analyzed in this report.

Although the July, 1995 heat wave is considered to be the worst ever in Chicago (Klinenberg, 2002), and it certainly was worse than any of the other heat waves we evaluated in terms of oppressiveness and mortality totals, our results indicate that the much more moderate heat wave of June, 1999 was responsible for a larger number of deaths than might be expected. The fact that the 1999 heat wave occurred in June certainly contributed to the heightened numbers, since a considerable amount of research shows that early season heat waves are more damaging to human health than late season counterparts (Auliciems, 1998).

Environmental modification, as modeled in this study, showed that two of the four heat waves did demonstrate significantly lower death totals; unfortunately, the July, 1995 heat wave was not one of these as temperatures were so high that no air mass changes occurred during this episode.[1] However, the July, 1988 and June, 1999 heat waves do show double-digit reductions in deaths, with about a 7 percent mortality decline in the former event. One of the heatwaves (June, 1999) parallels New York's results, where the two albedo reduction scenarios indicate the greatest mortality drops, with little change in the increased vegetation scenario. The 1988 event shows relatively even mortality declines in all three scenarios. Some of this can be attributed to air mass changes; in the 1999 event, June 9 switched from an oppressive MT+ to an MT for the two increased albedo scenarios. There was also a

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[1] The July 1995 heat wave in Chicago resulted in over 800 excess deaths (Klineberg, 2002). We only record 280 deaths since our four-day modeled period is a subset of the entire heat wave period during July 1995.

switch for June 8, but that was from one oppressive air mass (DT) to another (MT+), and no corresponding mortality reductions occurred. July 4, 1988 also showed an air mass switch for all three scenarios, but it is noteworthy that temperature reductions created by the modeled environmental modifications reduced mortality on virtually all of the days within this heat wave.

When evaluating Chicago and Detroit, the city with a similar climate evaluated in the previous study (Kalkstein and Sheridan, 2003), it is clear that the results from Chicago were more robust when compared to those obtained for Detroit. Chicago seems more sensitive than Detroit for a variety of reasons, some relating to urban structure (a larger number of densely-populated homes in poor areas) and others relating to climate (Chicago's summer weather is generally hotter than Detroit's, and the heat waves utilized in this study were more extreme in Chicago). However, when comparing these cities, please note that the modeling was performed by two different individuals (Sailor for Detroit; Taha for Chicago), and considering the differing assumptions utilized by these modelers, that could contribute to the differential in results.

Probably the most surprising results to come from this study was the lack of heat/mortality response in Baltimore (Figure 3). The number of heat-related deaths in this city is small, regardless of the magnitude of the heat wave. Even when afternoon temperatures approached 38 degrees C (100 degrees F), as they did on July 5-6, 1999, and when heat index values on these days were around 42 degrees C (108 degrees F), the number of excess deaths was less than 3 individuals. The weakness of this response is rather startling, especially considering the extreme responses in nearby cities like Philadelphia and New York. It is true that Baltimore is generally a warmer city than New York, with a lower summer temperature standard deviation. But the response differential is much too large to be explained only by this. In addition, Baltimore probably has a less densely-packed urban core than Philadelphia or New York, but without further investigation, it is speculation to attribute the response differences to this.

Regardless, any scenario modifications had little impact on Baltimore mortality response (Figure 7). Differences were less than a single death for all of the scenarios, although the differential was about 10 percent for the July, 1995 albedo reduction scenario, since the base number of heat-related deaths was so low.

Clearly, Baltimore cannot be considered as a similar response city to New York, Philadelphia, and probably to Boston as well. It would be interesting to determine Washington's heat/health relationship to see if it is rather flat like Baltimore's. That may determine that responses are different between cities in the northeastern U.S. and those in the mid-Atlantic region.

Houston, like New Orleans in the previous study, proved to be the city with the weakest heat/mortality relationship, and consequently, environmental modification had little impact in this city. In fact, Houston's response was even less than New Orleans, a heat insensitive city demonstrating little mortality increase during heatwaves. Considering the similarity in response for these two cities, we suggest that urban modifications as modeled in this study will have little impact on human mortality in the South. Of course, there are ancillary benefits related to increased vegetation and urban albedos. Indoor temperatures are still likely to be lower with these modifications, and aesthetics are improved. However, considering the better acclimatization of southerners as well as the greater proportion of people with air conditioning, it is not surprising that mortality changes were very modest in Houston and New Orleans.

Conclusions

In some ways, the results here confirm what we found in the earlier evaluation. For two of the cities, New York and Chicago, there was an important downturn in mortality under the modification scenarios. For one of the cities, Baltimore, there was very little response. And for Houston, there was no detectible response at all.

The following is a list of key findings, summarized in Table 6:

1. *Meteorological*
   - The thermal changes for New York and Baltimore are somewhat similar to what we found for Philadelphia in our previous study. Generally, the largest temperature drops occur within the high albedo scenarios, and the smallest differentials are associated with the high vegetation scenarios.
   - Greater temperature reductions occurred in the afternoon rather than the morning.
   - Thermal changes for all four evaluated cities are not very large, although they do exceed 1 degree C (1.6 degrees F) in some cases. This type of reduction could have an impact on mortality totals.
   - Dewpoint responses are generally smaller than temperature responses in all of the cities. This is similar to results found in the original study. However, mortality appears to be more sensitive to temperature changes than to dewpoint changes.

- For a majority of the days in the high vegetation scenario, there are very small increases in afternoon dewpoint temperature, something that we noted in the original study, and these could offset any temperature reductions.
- For a majority of the high albedo scenario days, there is a small decrease in afternoon dewpoint temperature.
- Apparent temperature alterations are generally less than 1 degree C for all scenarios.

2. *Mortality*

- Based on the mortality rate per population, Chicago appears to be the city in this study that is most sensitive to heat. New York has a high sensitivity as well.
- Baltimore has a surprisingly modest sensitivity, and Houston shows no response at all.
- For New York and Chicago, a few days switched air mass type from offensive to non-offensive, especially under high albedo scenarios. This led to large drops in mortality on those days.
- It is clear that higher albedo is more effective in lowering mortality in New York and Chicago than increasing vegetation cover.
- The mortality drops for the July, 1997 heat wave in New York exceed 20 percent, the best result obtained from all four cities. Two days altered air mass type during this heat wave.
- New York and Philadelphia (analyzed in the previous study) demonstrated very similar response under the modeled scenarios.
- Chicago mortality declines were significant with two caveats: the percentage drops were smaller than New York's, and drops were insignificant during the particularly oppressive heat wave of July, 1995.

- Chicago and Detroit (analyzed in the previous study) did not correspond as well as Philadelphia/New York.
- Since there were very small sensitivities between heat and mortality in Baltimore and Houston, any modifications did not have a significant impact in these cities.
- Baltimore's differential sensitivity with relation to Philadelphia and New York requires further investigation.

Table 6
A Summary of Results

Attribute	Baltimore	Chicago	Houston	New York
Scenarios Constructed	High Albedo, High Vegetation, Moderate Albedo + Vegetation			
Offensive Air Masses	DT MT+	DT MT+	DT MT+	DT MT+
Meteorological Changes with Cooling Scenarios	Largest temperature drops in the afternoon, particularly with high albedo scenario. Small increases in dewpoint in high vegetation scenario.	Some significant afternoon temperature drops, particularly in high albedo scenario. Little morning temperature change. Dewpoint response variable.	Significant afternoon temperature drops - high albedo scenario. Virtually no changes in morning temperature . General slight decrease in dewpoint.	Very similar to Baltimore.
Number of Days with Air Mass Changes	1 day from DT to MT+ (both offensive), 1 day from MT+ to MT (17 total days).	1 day from DT to MT+ (both offensive), 1 day from DT to DM, 1 day from MT+ to MT (all but high vegetation).	1 day from DT to MT+ (both offensive) (18 total days).	1 day from MT+ to MT (all but high vegetation), 1 day from DT to DM (19 total days).
Mortality Changes	Very small, generally less than 5%, not much sensitivity.	Significant for 2 of 4 heat waves - high albedo scenario; 1 of 4 heat waves - high vegetation scenario. Mortality reductions between 5-10 percent.	Virtually no changes, no sensitivity.	Greater than 10% reduction for 2 of 4 heatwaves. 20+% reduction for 1 heatwave. High albedo most effective. High sensitivity.

As in the previous study, the results here were mixed. It is clear that, in cities like Philadelphia, New York, Chicago, and Los Angeles, urban modifications that include increases in albedo will benefit the general population by reducing mortality totals. It can be assumed that this would also be the case for a number of other cities around the nation. Although aesthetically pleasing and beneficial in other ways, vegetation increases continue to show little positive impact on heat-related mortality. This was a common theme in both of our studies. We believe that this evaluation supports continued efforts to alter urban surfaces in an attempt to increase albedo within many major metropolitan areas.

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