J4.3

THE POTENTIAL OF URBAN ENVIRONMENTAL CONTROL IN ALLEVIATING HEAT-WAVE HEALTH EFFECTS IN FIVE US REGIONS

Haider Taha[1]
Altostratus, Inc.

Laurence S. Kalkstein
University of Delaware

Scott C. Sheridan
Kent State University

Eva Wong
U.S. Environmental Protection Agency

1. SUMMARY

Heat waves can cause severe thermal environmental stress leading to higher hospital admission rates, health complications, and increased mortality. These effects arise because of one or more meteorology-related factors such as higher effective temperatures, sunshine, more consecutive hot days and nights, stagnation, increased humidity, increased pollutant emissions, and accelerated photochemical smog and particulate formation.

Innovative urban-climate and environmental control strategies could be implemented to help reduce the local negative impacts of heat waves in the U.S. Short-term urban environmental controls, for example, include modifications to urban surface albedo, reforestation, and a reduction in anthropogenic heating. Long-term solutions could include smart growth strategies, land-use planning, land-cover control, urban design and geometry, passive solar systems, and transport-related actions. In this study, the focus is on increased urban surface albedo and, if suitable, local reforestation.

This meteorological and thermal environmental modeling study, currently in its initial stages, will examine the potential of short-term control strategies in reducing the impacts of heat waves in five U.S. regions (California, New York, Maryland, Illinois, and Texas). Work on the Los Angeles area has been completed and is underway for the other four regions.

This paper focuses on the initial findings for the Los Angeles Basin and Southern California. The results to date suggest that the above-discussed strategies could produce an urban-area averaged temperature reduction of up to 2K in south Los Angeles with corresponding average decrease of 0.2K in dew point temperature and changes of up to 1 m s^{-1} in wind speed. These meteorological changes can help reduce heat-related health problems. By analyzing several heat waves that have occurred within the past decade in the Los Angeles area, we estimate that such changes in meteorological conditions could have reduced heat-related mortality by up to 25%.

2. INTRODUCTION

Heat waves bring about higher temperatures, increased solar heating of buildings, inhibited ventilation, and a larger number of consecutive warm days and nights. All of these effects increase the thermal loads on buildings, reduce their ability to cool down, and increase indoor temperatures. Because heat waves in the U.S. have significant societal and health impacts, especially for the elderly in poor areas and in heavily built-up urban environments, it is important to address strategies that could alleviate their potential local impacts. One possible approach to minimizing the local effect of heat waves is to adopt innovative environmental controls, such as increased urban surface albedo, evaporative cooling, shading, and reduction in heat emissions. Modeling work to date and some limited field studies have suggested that increased urban albedo and reforestation can noticeably reduce surface and air temperatures under a range of summer meteorological conditions, e.g., Taha

[1]Corresponding author address: Haider Taha, Altostratus Inc., 940 Toulouse Way, Martinez, CA 94553, e-mail: haider@altostratus.com

(1999), Taha et al. (1999), Sailor (1993), and Taha (1996,1997).

These measures not only can improve the thermal environment, e.g., by reducing ambient air temperatures, but can also potentially improve air quality by slowing down the local rate of ozone formation (e.g., PAN decomposition rate) and meteorology-dependent emission of ozone precursors. Here we focus on the meteorological and thermal environmental impacts.

3. IMPACTS ON HEAT-RELATED MORTALITY

As part of an effort supported by the EPA, there is interest in determining whether the number and/or severity of days that are detrimental to human health within selected urban areas will decrease if the above-mentioned urban environmental control strategies are adopted. Previous research has indicated that "oppressive air masses" have been historically associated with increasing health problems related to heat, especially respiratory-related mortality, cardiac arrests, stroke, and of course, a variety of direct heat-related illnesses (Kalkstein, 1995). These air masses, most commonly an extreme form of dry tropical (DT) and moist tropical (MT) air, can be beyond the human threshold of tolerance in many locales, especially for the elderly and infirm. Each air mass has a differing means of affecting the vulnerable components of the population. The DT is the hottest and driest air mass, and its continued presence induces rapid moisture loss from the body, leading to dehydration. MT is not quite as hot but is more humid, inhibiting the ability of sweat to remove heat from the body. In either case, direct exposure to the air masses or remaining within un-air-conditioned indoor environments during their presence can lead to negative health outcomes.

Even if thermal alteration is not dramatic, it is possible that a change of only a few degrees in temperature might save a significant number of lives. Research has indicated that there is a large variation in urban mortality even within oppressive air masses, and that a 1-2K reduction in outdoor air temperature, along with some other meteorological changes, could reduce mortality by 10-20% (Chestnut et al., 1998; Kalkstein, 2000). There is every reason to believe that a similar reduction in indoor and outdoor temperature might have a similar impact; certainly, individuals would not be comfortable, but even subtle temperature changes may mean the difference between life and death.

Mortality data for the Los Angeles standard metropolitan statistical area were obtained for the period 1975 to 1998 (National Center for Health Statistics, 2001). As this research focuses on heat impacts, only the "summer" period, May 1 to September 30, was analyzed for each year. For each day, total mortality across a city's metropolitan area was summed. The 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 some cities, people leave town in August to go on vacation, thus lowering the daily mortality significantly – this decrease is included in standardization as it represents non-meteorological "noise").

Standardization yields 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, the evaluation proceeds using the newly-created anomalous mortality variable.

The weather data used in air mass classification development were supplied by NOAA's National Environmental Satellite, Data, and Information Service (2000) and were standardized by an air-mass classification procedure. This procedure determines which of a number of 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 the latest iteration to develop a state-of-the-art air mass classification procedure. Two air mass types, DT and MT+ (a more oppressive version of the MT air mass described above), are associated with statistically significantly higher mortality than the other air masses. 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 was developed for each offensive air mass in each city to predict excess mortality. These correlations accounted for:

1) Time of season,
2) Persistence of an oppressive air mass, and
3) Air mass character, including temperature, humidity, and cloud cover.

4. METEOROLOGICAL MODELING

The first step in this study involves characterizing the meteorological modeling domain in terms of general surface properties, land use/land cover (LULC), topography, water/land distribution, and certain "thermophysical" properties of relevance to the proposed control strategies, such as surface albedo, thermal inertia, soil moisture, and roughness length. Global data and region-specific survey information are combined. In this study, the default USGS LULC input to the meteorological model (MM5) is used in the coarse modeling grid but is ignored in the finer grids and where urban land use exists near and in the areas of interest, i.e., the metropolitan regions being modified. In these areas, the standard input to the model is overridden with finer resolution and multi-category *urban* LULC thus replacing the single urban category typically used in the MM5 (Taha 2003). The input for the target urban areas thus consists of thermophysical properties (not LULC) externally computed and directly inputted into the model to override the default gridded input.

Starting at a spatial resolution of ~200 m, these parameters are computed for every cell, then averaged to and gridded at the model's resolution (e.g., 2km). Following this methodology, these parameters are then re-computed and re-specified for each surface-modification control scenario, e.g., changes in albedo and vegetation fraction. Example base and modified values are computed based on **Table 1** (e.g., Taha 1996,1997; Taha et al. 1999).

Table 1: Assumed 200-m albedo and soil moisture values

		A	B	C	D	E
Urban LULC	USGS LULC Classification	Base albedo	Moderate albedo	High albedo	Base soil moisture	Moderate soil moisture
11	Residential	.157	.217	.278	.12	.131
12	Commercial/Services	.139	.252	.366	.10	.132
13	Industrial	.152	.242	.332	.10	.104
14	Transportation/Communications	.117	.245	.374	.10	.102
15	Industrial and commercial	.152	.242	.332	.10	.108
16	Mixed urban / built up	.134	.207	.281	.11	.116
17	Other urban / built up	.134	.207	.281	.10	.109

In section 6, results from two control scenarios are presented. The first is a combination of moderate increases in albedo and vegetative cover (values in columns B and E of Table 1) and will be referred to as Case 11, whereas the second involves only large increases in albedo (column C), and will be referred to as Case 20.

In addition to surface characterization, other information that must be supplied to the meteorological model includes, for example, initial and boundary conditions. In this study, these were extracted from the NCAR NCEP Reanalysis project (NNRP) data sets as appropriate for the selected episodes and domains.

The meteorological modeling in this study is performed with the PSU/NCAR MM5 (Dudhia 1993). For this application, the model is run with the 24-category USGS LULC as a default in the coarse grid, except near the modifiable target areas, where region-specific data is used to override the USGS LULC, as explained above. Several different sets of model options were evaluated. For the current results, the model was run with the MRF boundary-layer option and a stable precipitation scheme for moisture. FDDA was not used in the modeled boundary layer so as to minimize impact on the desired signal (impacts of changes on temperature and other meteorological fields) as much as possible. The model was run with 29 vertical levels with fine resolution near the ground to capture the effects of interest. The horizontal resolution is 2 km. For a discussion of options and configurations, see Taha (2003).

5. DOMAINS and EPISODES

The simulations were performed for the episodes listed in **Table 2**. The modeling domain is shown in Figure 1. In this paper, simulation results from sub-domain D06 (Los Angeles Basin) are presented. Model performance for this domain and episode are discussed elsewhere, e.g., Taha (2004).

6. RESULTS

Figure 2 shows an example snapshot of results, e.g., a horizontal cross section of the difference in air temperature at 2 m above ground level (AGL) on 8/30/98 resulting from implementing increased urban albedo. Two hour intervals are shown. At 0900, the Los Angeles area is about 1.75K cooler than the base conditions, whereas the San Diego region is up to 2K cooler.

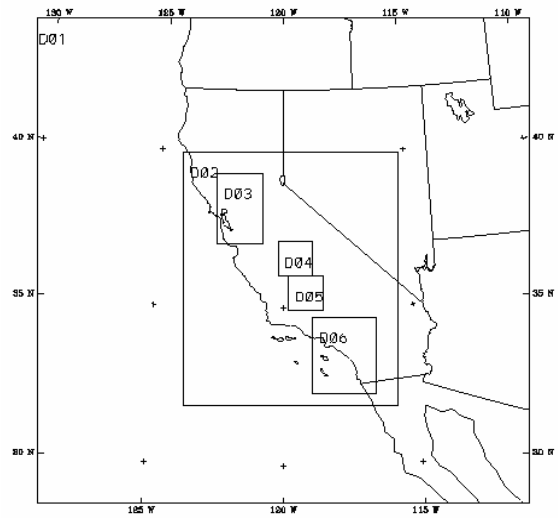

Figure 1. California modeling domain (domain D06 is discussed in this paper).

At 1300, areas in the Los Angeles Basin can be 2K cooler and in San Diego up to 0.75K cooler than the respective base case conditions. Beginning at 1700, there is some warming in certain areas, caused primarily by changes in the wind field (weaker onshore flow). These “snapshot” characterizations of air-temperature changes show the spatial extent of the impact due to implementation of urban environmental control but do not capture the entire range of temperature response characteristics.

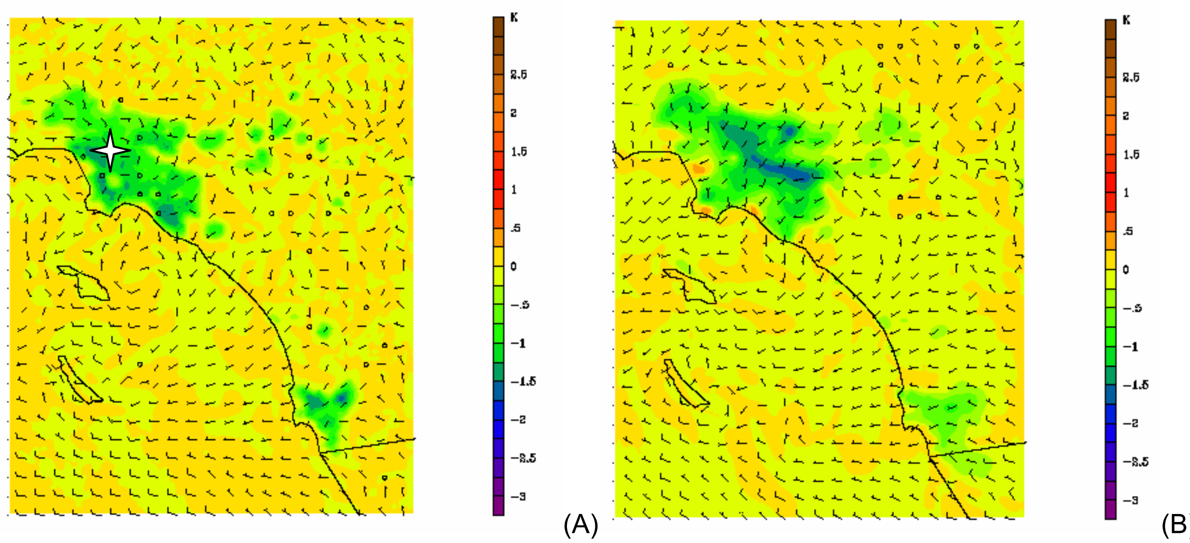

Figure 2: Difference in air temperature (K) at 2 m AGL in the Los Angeles and San Diego regions at (A) 0900 and (B) 1300 PDT 8/30/98. Full barb is 5 m s^{-1}. The star in figure (A) shows South Los Angeles.

Thus for the purpose of analyzing the health impacts and the potential of the proposed control strategies in offsetting the local effects of heat waves, the changes in relevant meteorological fields, e.g., temperature, wind, and dew point, were averaged over an area of interest (150 km^2 in

South Los Angeles) and presented as time series in Figure 3. The location of the star in Figure 2 (A) depicts South Los Angeles. The time series are shown below for Case 11 (red lines) and Case 20 (blue lines), for the episodes defined in Table 2.

Table 2: Episode definition for Southern California simulations

Episode number	Dates included (00 through 00 UTC)	Number of days
0	08/29 through 09/01/1998	3.3
1	10/08through 10/12/1994	4
2	10/14through 10/18/1997	4
3	08/10through 08/17/1994	7
4	08/29through 09/05/1998	7
5	09/29through 10/02/1999	3

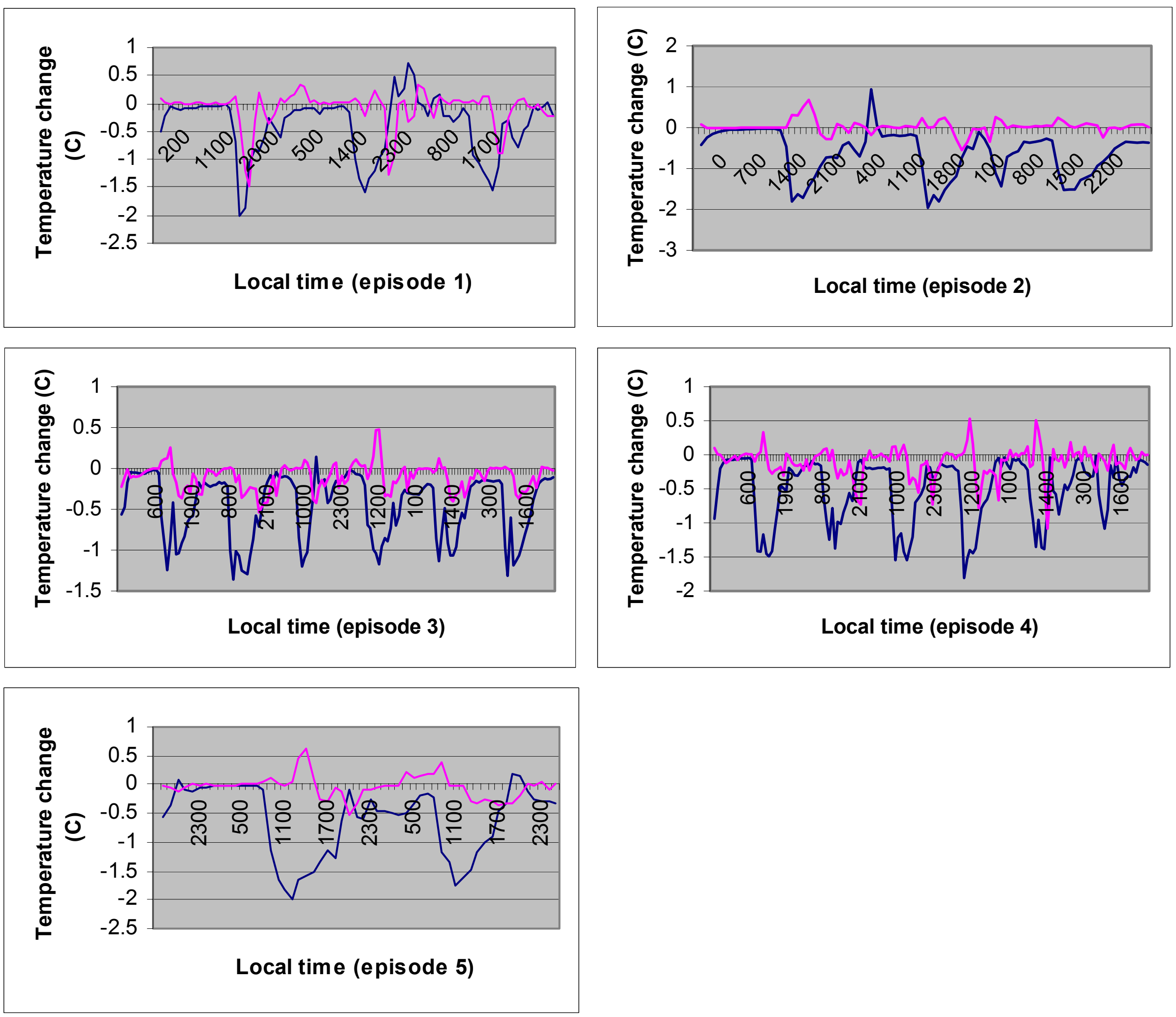

Figure 3: Area averaged air-temperature changes (K) (averaged over an area of 150 km^2 in South Los Angeles) for episodes 1 through 5, for cases 11 and 20 as defined above.

The area-averaged temperature decrease reaches up to 2K, which is significant considering the averaging area (150km^2). The results suggest that large increases in albedo (case 20) are relatively more effective in cooling the air than combined moderate increases in albedo and vegetative cover (case 11). However, in some episodes and days, the effects can be comparable. There is also a timing difference, whereby the largest decreases in air temperature for Case 11 occur later during the day than for Case 20, which may be more advantageous from an air-quality point and heat-health perspective. As seen in **Figure 3**, the decrease in area-averaged air temperature for Case 20 is largest during the hours of 1000-1100 and 1700-1800. In-between, there are relatively smaller decreases in air temperature, probably caused by changes in the wind field. In the last episode, the decrease in air temperature is relatively persistent from about 1000 through 1800 hours (PDT). For Case 11, the largest decrease in air temperature is typically delayed relative to that in Case 20, due to the effects of increased soil moisture on heat storage. Thus overall, the largest decrease is between 1500 and 1600 hours.

In Figure 4, the attending changes in dew point temperature and wind speed are shown for episode 1 only (as an example). It can be seen that for case 20, the decrease is in the order of 0.2K and is greater for the large-albedo increase scenario. In case 11, however, dew point temperature can increase as well. Changes in wind speed are up to -1 m s^{-1}. Table 3 shows the episode average changes in area-averaged parameters (averaged over all hours during the episodes defined in Table 2 and over 150 km^2). Shown are averages for cases 11 and 20, as defined above.

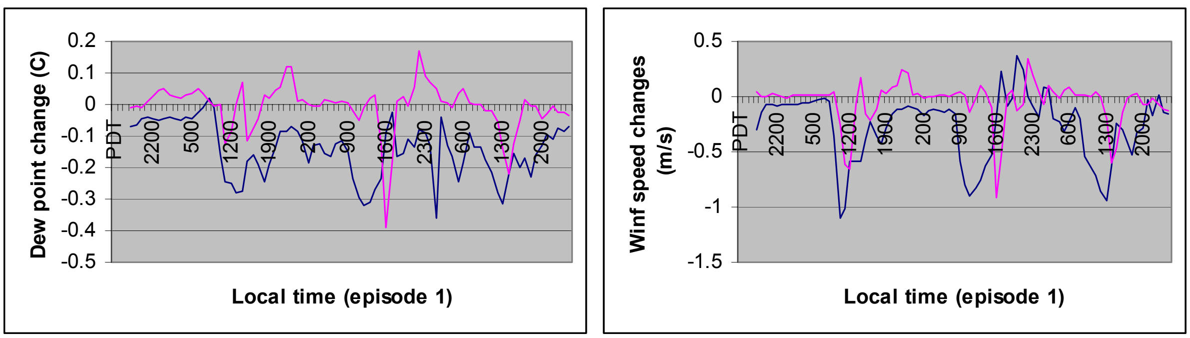

Figure 4. Area averaged dew-point temperature (K) and wind speed (m s^{-1}) changes for Los Angeles (averaged over an area of 150 km^2) for episode 1 for cases 11 and 20 defined above.

Table 3. Area- and episode-averaged changes in temperature, dew point temperature, and wind speed in South Los Angeles.

	Case 11			Case 20		
	ΔT (K)	Δdew (K)	Δwsp (m s^{-1})	ΔT (K)	Δdew (K)	Δwsp (m s^{-1})
Episode 1	-0.09	-0.01	-0.04	-0.39	-0.14	-0.27
Episode 2	0.02	0.01	0.01	-0.62	-0.17	-0.39
Episode 3	-0.10	-0.03	-0.07	-0.46	-0.16	-0.32
Episode 4	-0.10	-0.03	-0.07	-0.51	-0.17	-0.36
Episode 5	-0.04	0.00	-0.02	-0.61	-0.16	-0.38

For assessing potential health implications, the above-defined heat waves were evaluated (Table 4). Two of the heat waves (October, 1994; October, 1997) were of the typical “Santa Ana” type, and were dominated by DT air masses, while another two (August, 1994; August, 1998) were of the less common hot, humid type, that sometimes occurs when warm, moist air is transported into the region from the Gulf of California. As defined earlier, two mitigation scenarios (cases 11 and 20) were evaluated for all heat waves.

Table 4 indicates that atmospheric conditions were generally significant enough in terms of health impacts. In a few cases, especially within the hot, humid heat waves, a few days actually shifted air masses into cooler and more comfortable types. For example, in one of the scenarios for the August, 1994 heat wave, two of the days shifted from the MT air mass to the less stressful dry moderate (DM) air mass type. Mean daily mortality for offensive air masses (assuming no environmental control in place) were well above the summer baseline for the two offensive Los Angeles air masses. For DT air mass, during a meteorologically average day, there are 18 extra deaths. The value is slightly lower for MT+, 14 extra deaths during an average day.

For the modeled control scenarios, the results suggest that the impact of increased albedo (case 20) is significant, and mortality reductions appear to be sizable within the humid heat waves, with reductions of 14 deaths in August 1998 (approximately 25%), and a similar number (approximately 17%) in the August 1994 heat wave. Moderate albedo increases coupled with moderate increasing vegetation (case 11) appear to have a more limited, but still notable, impact on reducing mortality during these humid heat waves. This lesser effect might be attributed to the impact of increasing vegetation upon dew-point temperature, which seems to be relatively unchanged from the baseline within the higher vegetation scenario.

During the hot and dry heat waves, mortality changes appear to be smaller, fewer than 3 deaths, and the thermal changes associated with both increasing albedo and vegetation seem very small during DT air mass days in Los Angeles. Comparing the two different scenarios (cases 11 and 20) during DT heat waves, the high albedo scenario is associated with a greater reduction of mortality than the vegetation/moderate albedo scenario. This is similar to the results during the humid heat waves, and appears to suggest that increasing albedo has a more significant mitigating effect than increasing vegetation alone.

There are several important air mass changes that occur under the high albedo scenario (case 20). During the August, 1994 heat wave for example, three of the days changed to less oppressive air mass types, and this significantly lowered the mortality totals for this heat wave. However, under scenarios of case 11, these days shifted back to the offensive air mass because of temperature and dew-point increases.

7. CONCLUSION

This paper presented some aspects of work in progress in quantifying the potential impacts of urban environmental control strategies in alleviating the local health effects of heat waves. Results obtained so far suggest beneficial impacts in Southern California/Los Angeles. Ongoing work in this study will evaluate the potential impacts of these strategies in four other US regions. These impacts on meteorology and health will be quantified and together used to develop an initial basis for implementation proposal.

Table 4. Episodic air masses and potential impacts on air and dewpoint temperatures.

DAY	OBSERVED					Case 20					Case 11				
	Air Mass	T02	T14	Td14	Fore. Mort	Air Mass	T02	T14	Td14	Fore. Mort	Air Mass	T02	T14	Td14	Fore. Mort
10-Aug-94	MT	21.7	27.8	15.6	8.1	DM	21.6	26.8	15.3	6.0	MT	21.7	27.5	15.5	7.4
11-Aug-94	MT	21.7	27.2	16.1	6.7	DM	21.5	25.9	15.7	4.0	MT	21.7	26.9	15.8	6.1
12-Aug-94	MT	20.0	28.9	18.6	10.3	MT	19.9	29.0	18.3	10.5	MT	20.0	28.5	18.1	9.4
13-Aug-94	MT+	24.4	31.1	17.2	28.9	MT+	24.4	30.2	16.9	25.7	MT+	24.4	30.8	17.1	27.8
14-Aug-94	MT+	23.3	28.9	20.0	17.9	MT	23.0	27.8	19.7	14.3	MT+	23.3	28.5	19.9	16.5
15-Aug-94	MT	22.2	29.4	16.7	11.2	MT	22.1	28.4	16.5	9.1	MT	22.2	29.1	16.6	10.5
Total					**83.1**					**69.5**					**77.9**
8-Oct-94	DT	17.8	33.9	4.4	5.4	DT	17.7	33.1	4.1	5.1	DT	17.8	34.1	4.5	5.4
9-Oct-94	DT	22.2	35.6	4.4	20.4	DT	22.0	34.6	4.1	19.7	DT	22.2	35.7	4.4	20.4
10-Oct-94	DT	23.3	31.1	5.0	24.1	DT	23.4	30.0	4.8	24.5	DT	23.4	30.2	4.8	24.5
Total					**49.9**					**49.2**					**50.3**
14-Oct-97	DT	20.6	35.0	-0.6	14.9	DT	20.6	33.8	-0.9	14.9	DT	20.6	35.3	-0.6	14.9
15-Oct-97	DT	23.3	34.4	2.8	24.1	DT	23.1	33.0	2.5	23.4	DT	23.3	34.4	2.8	24.1
16-Oct-97	DT	23.9	31.1	8.3	26.2	DT	23.3	29.9	8.0	24.1	DT	23.9	31.2	8.3	26.2
Total					**65.2**					**62.5**					**65.2**
8/29/1998	MT	20.0	28.9	16.7	9.3	MT	20.0	27.5	16.3	6.3	MT	19.9	28.6	16.6	8.6
30-Aug-98	MT	22.8	29.4	18.9	10.3	MT	22.6	28.4	29.1	8.2	MT	22.7	29.2	18.8	9.9
31-Aug-98	MT	21.1	27.2	19.4	5.5	MT	20.9	25.8	19.0	2.6	MT	21.1	26.8	19.3	4.7
1-Sep-98	MT+	22.2	28.3	20.0	12.6	MT	22.0	27.3	19.7	8.7	MT	22.2	27.5	19.8	9.0
2-Sep-98	MT	22.2	27.2	20.0	5.4	MT	22.1	26.4	19.7	3.7	MT	22.2	26.1	19.8	3.1
3-Sep-98	MT+	22.2	29.4	19.4	16.5	MT+	22.1	29.4	19.1	16.2	MT+	22.1	29.3	19.3	15.8
Total					**59.6**					**45.6**					**51.1**

8. REFERENCES

Chestnut, L.G., W.S. Breffle, J.B. Smith and L.S. Kalkstein, 1998: Analysis of Differences in Hot-Weather-Related Mortality across 44 U.S. Metropolitan Areas. *Environmental Science and Policy*, **1**, 59-70.

Dudhia, J. 1993: A non-hydrostatic version of the Penn State/NCAR mesoscale model: Validation tests and simulation of an Atlantic cyclone and cold front. *Monthly Weather Review*, **121**, 1493-1513.

Kalkstein, L.S., 1995: Lessons from a Very Hot Summer. *The Lancet*, **346**, 857-859.

Kalkstein, L.S., 2000: Saving Lives During Extreme Weather in Summer. *British Medical Journal - Editorials*, **321**, 650-651.

National Center for Health Statistics, 2001: Multiple cause-of-death mortality data for Philadelphia, PA. Hyattsville, MD. U.S. Department of Health and Human Services, Center for Disease Control and Prevention. http://www.cdc.gov/nchs

National Environmental Satellite, Data, and Information Service, 2000: TD-3280 U.S. Surface Airways and Airways Solar Radiation Hourly. Washington, D.C. U.S. Department of Commerce.

Sailor, D. 1993: Role of surface characteristics in urban meteorology and air quality. Doctoral Dissertation, University of California – Berkeley.

Sheridan, S.C., 2002: North American weather type frequencies and teleconnections. *International Journal of Climatology*, **22**, 51-68.

Taha, H. 2004: Urban surface modification as a potential ozone air-quality improvement strategy in California airsheds, Draft Final Report prepared for the California Energy Commission. Altostratus Inc., Martinez, California.

Taha, H. 2003: Mesoscale meteorological and air quality modeling of heat island reduction strategies (HIRS), Technical Note, Lawrence Berkeley National Laboratory, Berkeley, California (April 2003).

Taha, H. 1999: Modifying a Mesoscale Meteorological Model to Better Incorporate Urban Heat Storage: A Bulk-Parameterization Approach. *Journal of Applied Meteorology*, **38**, 466-473.

Taha, H., S. Konopacki, and S. Gabersek, 1999: Impacts of large-scale surface modifications on meteorological conditions and energy use: A 10-region modeling study. *Theoretical and Applied Climatology*, **62**, 175-185.

Taha, H. 1997: Modeling the Impacts of Large-Scale Albedo Changes on Ozone Air Quality in the South Coast Air Basin. *Atmospheric Environment*, **31**, 1667-1676.

Taha, H. 1996: Modeling the Impacts of Increased Urban Vegetation on the Ozone Air Quality in the South Coast Air Basin. *Atmospheric Environment*, **30**, 3423-3430.