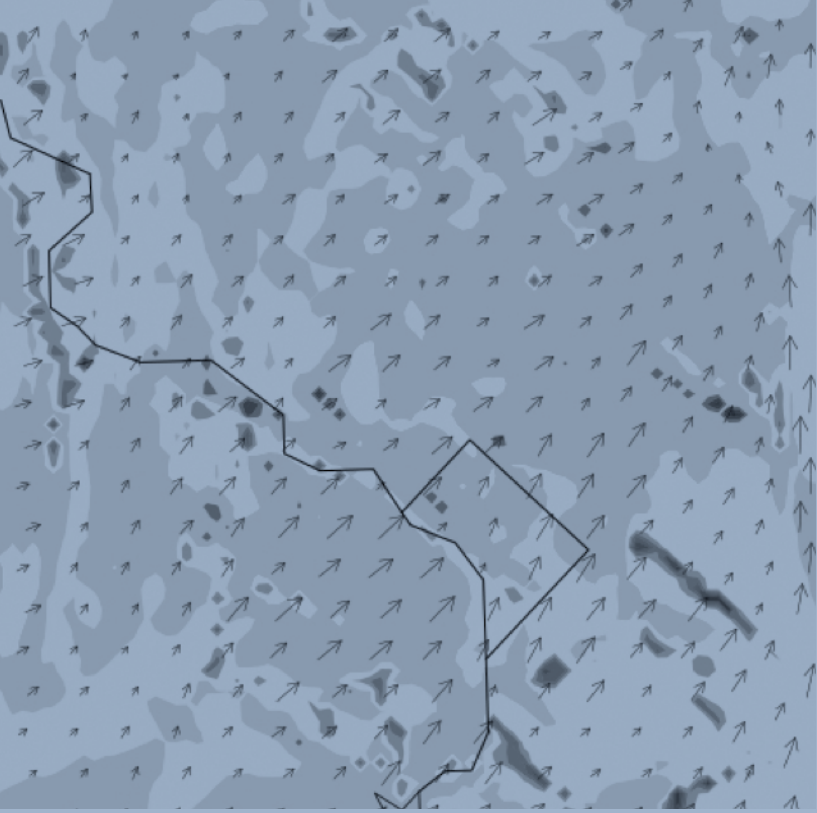




Assessing the **Health Impacts of Urban Heat Island Reduction Strategies** *in the District of Columbia*

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SUMMARY

Purpose

The District of Columbia is susceptible to extreme heat events whose health impacts are exacerbated by the fact that the city is often significantly warmer than surrounding rural areas during the summer. Research from studies of other cities has indicated that measures to reduce excess urban heat (known as “urban heat islands”) can have a positive impact on weather conditions and health during extreme heat events. Many such measures are already a part of District policy, including promoting cool roofs and pavements that reflect sunlight rather than absorb it as heat and installing green roofs, shade trees, and vegetation to provide shade and other cooling benefits.

Activities Undertaken

This study estimates possible reductions in heat-related mortality in the District assuming the installation of urban heat island reduction measures and determines if the number of days with weather conditions that are historically associated with high mortality will decrease significantly using cooling strategies. The study team identified four actual multi-day heat events, calculated excess mortality during those events, and modeled the impact of increased surface reflectance and increased vegetative cover on meteorological conditions and expected mortality.

Outcomes

The study found that a 10-percentage point increase in urban surface reflectivity could reduce the number of deaths during heat events by an average of 6%. Adding a 10% increase vegetative cover to the increases in reflectivity yielded an average 7% reduction in mortality during heat events. During the decades between 1948 and 2011, an average of 285 people died of heat-related causes (Kalkstein et al., 2011). A 6–7% decrease in mortality would save approximately 20 lives per decade. In addition, an even larger reduction would be expected in hospital admissions from heat-related illness, although this was not a specific finding of this analysis. Changes in temperature and humidity (as measured by dew point temperature) in both scenarios were relatively minor, yet were significant enough to contribute to the reduction of deaths.

The District, given its current policy landscape and development, could achieve the increases in reflectivity and vegetation used in this study. Increasing District-wide roof reflectivity by 10 percentage points is achievable by converting dark grey roofs to white roofs on approximately 25 percent of the District’s buildings. Assuming the average roof lasts 20 years, the District could achieve this with end-of-life roof replacements in slightly more than 5 years. Achieving the same increase in reflectivity for pavements would require the conversion of 50 percent of District pavements from dark asphalt to a slightly lighter option like grey concrete. A significantly smaller percentage of pavements would need to be converted if cool coatings were applied where feasible.

INTRODUCTION

The Problem of Extreme Heat

Annually, heat kills more than 1500 people in the United States, more than any other natural disaster in an average year. The District is particularly susceptible to extreme heat events because its downtown is sometimes 10–15 degrees hotter on summer afternoons than surrounding rural areas. This so-called urban heat island effect (“UHI”) occurs for a number of reasons:

- On average, more than 50% of urban landscapes are dark man-made surfaces that get hotter in the sunlight than natural landscapes (e.g., grass, tree canopy).
- Cities have less vegetation than rural areas. Vegetation keeps temperatures lower than man-made surfaces by providing evaporative cooling and shade.
- Urban areas are centers of human activity, many of which generate heat (e.g., air conditioning exhaust, vehicles, industrial processes)

In addition to causing higher daytime temperatures, urban heat islands keep cities and their residents from cooling off at night. Hotter nighttime temperatures are especially dangerous during extreme heat events. Urban populations are often unable to recover from the daytime heat and become more vulnerable to heat-related health problems in subsequent days.

Applied Climatologists Inc (ACI)’s previous research has determined that certain very hot, dangerous “oppressive air masses” are associated with statistically significant increases in heat-related mortality, especially from cardiac arrests, strokes, and other heat-related causes (Kalkstein et al., 2011, and other manuscripts). These air masses, most commonly extreme forms of Moist Tropical (MT+) and very hot, dry tropical (DT) masses (see Table 1 for descriptions of air masses), are beyond the human threshold of tolerance in many locales, especially when they occur in consecutive days.

From 1948 to 2011, an average of 11% of summer days in the District were considered “oppressive.” However, the days with air masses that lead to heat warnings and health problems are happening more and more frequently. In the 1950s and 1960s, the District experienced these “dangerous” air masses about 7–10 days each summer (approximately 8–10% of the summer). During the last decade, those dangerous air masses have been occurring on 16 summer days (approximately 18% of the summer).¹

Dangerous summer days have been even more common in the District during the last three years, with 33 days in 2010, 28 days in 2011, and 27 days in 2012 (Sheridan, 2013). The District experienced its hottest month on record in July 2011, including a record 25 days above 90 degrees Fahrenheit.

These heat waves take a disproportionate toll on people of color and low-income urban populations that often live in neighborhoods that have older, lower quality building stock, less tree cover, and fewer buildings with air conditioning. A new study (Jesdale et al, 2013) finds that Black Americans are 52% more likely than average to live in areas where a high risk for heat-related health problems exists. Hispanic Americans are 21% more likely to live in such conditions. Mitigating urban heat islands and the impact of extreme heat will help the District improve health equity, increase social justice, and become more sustainable.

1. More details on historical air mass characteristics for the District are found on Dr. Scott Sheridan’s website: <http://sheridan.geog.kent.edu/ssc.html>

MITIGATING URBAN HEAT ISLANDS

This study evaluated two common urban heat island mitigation strategies—increasing reflectance and increasing vegetative cover.

Increased Reflectance

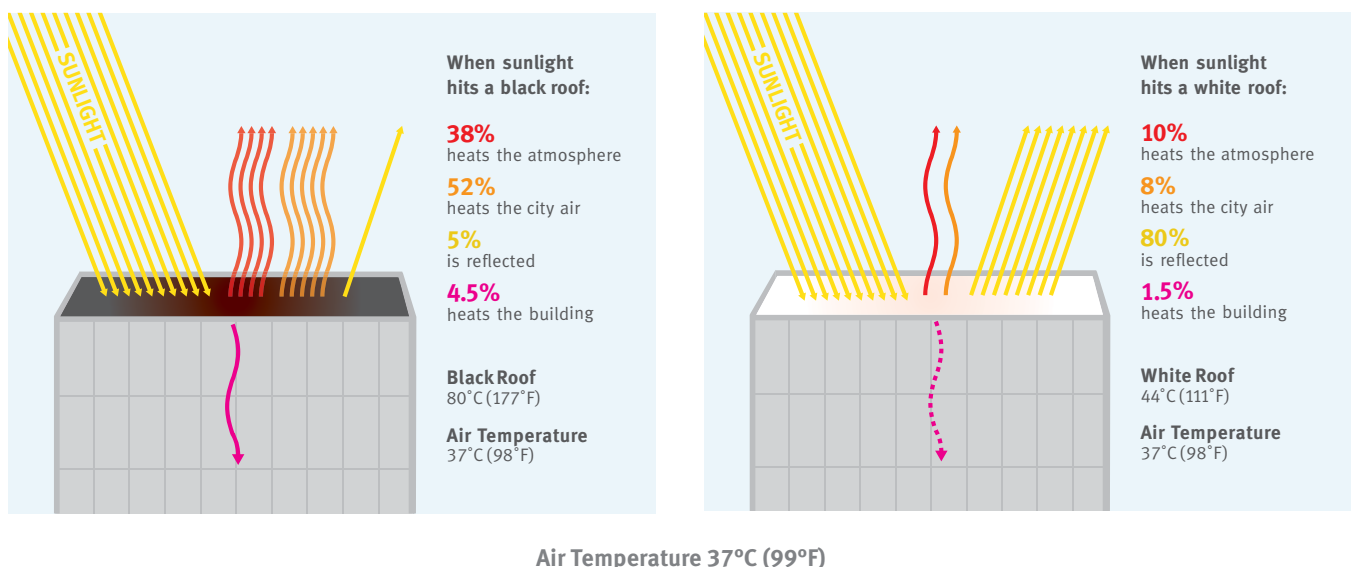
Studies indicate that roofs and pavements make up 60% to 70% of urban surfaces in an average U.S. city. About 20% to 30% are roofs and 30% to 45% are pavements (Akbari et al., 2009). Often, these surfaces are dark and will typically absorb more than 80 percent of sunlight. Solar energy absorbed by roofs becomes heat that can be transferred into the building or blown off the roof to heat the surrounding community.

Replacing and upgrading roofs and pavements with more reflective materials reverses this warming, turning urban surfaces into assets instead of burdens. Cool surfaces are measured by how much light they reflect (solar reflectance or SR) and how efficiently they radiate heat (thermal emittance or TE). Solar reflectance is the fraction of sunlight (0 to 1, or 0% to 100%) that is reflected from a surface. SR typically ranges from about 0.04 (or 4%) for charcoal to 0.9 (or 90%) for fresh snow. Solar reflectance is also referred to as albedo. High solar reflectance is the most important property of a cool surface.

Thermal emittance (TE) measures the efficiency (0 to 1) with which a surface emits thermal radiation. High thermal emittance helps a surface cool by radiating heat to its surroundings. Nearly all nonmetallic surfaces have high thermal emittance, usually between 0.80 and 0.95. Uncoated metal has low thermal emittance, which means it will stay warm. An uncoated metal surface that reflects as much sunlight as a white surface will stay warmer in the sun because it emits less thermal radiation. TE is the second most important property of a cool surface.

Figure 1 demonstrates how albedo can keep a surface cool. The figure depicts two identical roofs that are receiving the same amount of sunlight. On both roofs, a portion of the sunlight will heat the building, some will heat the city air, some will heat the upper atmosphere, and some will be reflected into space. The white roof reflects the vast majority of the sunlight back into space, thus keeping the building, city, and planet cooler.

Figure 1. Difference in heat dispersal on a black versus white roof. Much more heat is reflected when utilizing white roofing material. Source: Lawrence Berkeley National Lab



Increased Vegetated Cover

Vegetated cover can be increased in a number of ways, including vegetated roofs and shade trees. Trees and other types of vegetated cover also cool through evapotranspiration—a process by which vegetation releases water into the atmosphere through their leaves. Evapotranspiration can cool by using heat from the air to evaporate water. A tree canopy cools cities by shading the ground and structures around them. It is also possible to capture some of the evaporative cooling benefits with permeable or pervious pavement technologies. These pavements allow water to pass through them more easily than traditional pavements and can release some of that water back into the air.

The cooling effects of vegetation can be significant. Studies indicate that tree groves can be 9 °F cooler than open, grassy areas around them (Kurn et al., 1994). The USEPA’s *Reducing Urban Heat Islands: A Compendium of Strategies* reported: “Chicago compared summertime surface temperatures on a green roof with a neighboring building. On an August day in the early afternoon, with temperatures above 90 °F, the green roof surface temperature ranged from 91 to 119 °F while the dark, conventional roof of the adjacent building was 169 °F. The near-surface air temperature above the green roof was also about 7 °F cooler than the conventional roof.”

Table 1. Air mass types in the SSC

The DT and MT+ air masses are of greatest concern for increasing mortality when they are present in the District.

<i>Air Mass</i>	<i>Definition</i>
Generally Non-Oppressive Air Masses	
Dry Polar (DP)	Arrives from polar regions and is usually associated with the lowest temperatures observed in a region for a particular time of year as well as clear, dry conditions.
Dry Moderate (DM)	Consists of mild and dry air. It occurs when westerly winds warm the air as it descends the eastern side of mountain ranges.
Moist Polar (MP)	Typically cloudy, humid, and cool. MP air appears when air over the adjacent cool ocean is brought inland by an easterly wind, frequently during stormy conditions.
Moist Moderate (MM)	Considerably warmer and more humid than MP. The MM air mass typically appears in a zone south of MP air, near an adjacent stationary front (an area where warm air moves over a cooler air mass).
Moist Tropical (MT)	Warm and very humid. It is typically found in warm sectors of mid-latitude cyclones or in a return flow on the western side of a high-pressure area, such as the Bermuda High.
Transition (TR)	Defined as days in which one weather type yields to another, based on large shifts in pressure, dew point, and wind over the course of the day.
Oppressive Hot Air Masses	
Dry Tropical (DT)	Represents the hottest and driest conditions found at any location. There are two primary sources of DT: either it is transported from the desert regions, such as the Sonoran Desert, or it is produced by rapidly descending air.
Moist Tropical+ (MT+)	Hotter and more humid subset of MT. It is defined as an MT day where both morning and afternoon temperatures are above the MT averages, and thus captures the most “oppressive” subset of MT days. We have also identified an MT++ situation, which is even more extreme; in this case, both morning and afternoon temperatures are at least 1 standard deviation above MT averages.

METHODOLOGY

The research team on this report has worked with the National Weather Service on guidance to accurately determine excessive heat warnings for the District region. In addition, we have published results on our heat/health research in the District, as well as other cities around the country (Kalkstein et al., 2011). The methods employed by the team identify those oppressive air masses that have historically killed people in greater numbers during excessive heat events.

Air Mass Classification and Excess Deaths

Weather data for this study were supplied by NOAA's National Environmental Satellite, Data, and Information Service (2012) and we classified each day for the District into an air mass category using the *spatial synoptic classification* (SSC; Sheridan, 2002). The SSC evaluates a broad set of meteorological conditions to place each day into one of a number of air mass types listed in Table 1. The study focused on days when the District experienced MT+ and DT air masses. Daily mortality data are available for the entire US in digital format for the period 1975 through 2009 (Centers for Disease Control, 2012). As this research focuses on heat, only the “summer” period, May 1 through September 30, is analyzed. Total mortality across the District are summed for each day and then standardized to account for demographic changes in population characteristics during the period. Factors that cause growth or a decline in overall death rate for reasons unrelated to weather must be accounted for in the standardization of mortality. For example, daily mortality may be significantly lower in August, when people tend to go on vacation.

After standardization, mean anomalous daily mortality—the number of deaths above what would normally be expected on that day—is calculated for each air mass type. As has been the case in most cities, the DT, MT+, and MT++ air masses are associated with the greatest increase in mortality over baseline levels, although the degree of increase varies from one city to the next (See Table 3). During the period between 1948 and 2011, these oppressive air masses occurred on about 11% of the days during a typical summer in the District, and increased daily mortality on average by about 7 percent. During the last 10 years, however, these oppressive air masses have been occurring on approximately 18% of summer days.

Table 2: Summer days in the District with offensive, dangerous air masses present

Years	Average Summer Offensive Days	% of Total Summer Days
1942 to 1951	7.6	8.3%
1952 to 1961	9.7	10.5%
1962 to 1971	7.4	8.0%
1972 to 1981	13.9	15.1%
1982 to 1991	14.4	15.7%
1992 to 2001	15.6	17.0%
2002 to 2011	16.2	17.6%

Table 3. Mortality responses in different cities when DT and MT+ air masses are present. In the District, these air masses occur, on average, 11 percent of the time during the summer (June–August²). During a typical MT+ air mass day, mortality increases by about 7 percent in the District, or approximately 1.7 deaths above the average death rate.

City (% frequency JJA)	DT Mortality (% Inc)	MT+ Mortality (% Inc)
Washington (11%)	+0.9 (4%)	+1.7 (7%)
Seattle (6%)	+3.7 (8%)	+4.7 ^a (10%)
New York (11%)	+16.6 (7%)	+16.9% (7%)
New Orleans (2%)	None	+3.7% (9%)
Phoenix (1%)	+2.7 ^b (7%)	None
Rome (11%)	+6.2 (14%)	+5.0 (12%)
Shanghai (11%)	None	+42.4 (10%)
Toronto (7%)	+4.2 (11%)	+4.0 (10%)

2. The definition of the summer season differs from this study. June, July, and August are consistently summer months for the cities in this table and chosen to improve comparisons across cities.

^a MT+ does not occur in Seattle; the moist air mass that is present is MT. ^b DT+ air mass for Phoenix.

However, not all DT, MT+, and MT++ days result in elevated mortality. To account for this variability, a stepwise linear regression³ is developed for each offensive air mass to estimate excess mortality. These equations account for the following:

- Time of season. Historically, heat waves earlier in the summer season are more dangerous than those later in the season.
- Persistence of an oppressive air mass. Several consecutive days of an offensive air mass are much more health-debilitating than any single-day heat event.
- Air mass character, including temperature, humidity, wind speed, and cloud cover.

Cooling Simulations Employed

Dr. David Sailor of Portland State University provided modeled meteorological data for several different scenarios to test the impacts of urban cooling initiatives upon air mass character and heat-related mortality. The modeled data permitted us to determine air mass type and character for a variety of cooling scenarios and changes to the urban fabric (e.g., built versus natural space). The modeled data also allowed us to evaluate how adding urban vegetation changes the way the built and natural environment uses solar energy.⁴ We provided Dr. Sailor with the locations of areas within the District that possess a majority of the population most vulnerable to heat-related health problems (usually the lowest-income sections of the city in terms of economics and housing stock).

A regional scale (mesoscale) atmospheric model known as the Weather Research and Forecasting (WRF version 3.4) model was used for all atmospheric modeling in this project. WRF is widely accepted as one of the leading atmospheric models for both operational forecasting and climate research purposes. Details of WRF can be found at www.wrf-model.org and in numerous peer-reviewed research publications. WRF is typically used

with grid resolutions equal to or greater than 1 km, and as such, does not explicitly resolve the detailed geometry of urban areas (e.g. individual buildings). Rather, WRF allows the user to represent urban areas through one of several urban parameterizations. In this modeling we use the single layer urban canopy model (UCM) which allows for representation of roofs, walls, and streets in three classes-of urban areas: commercial/industrial, low density residential, and high-density residential.

To simulate the urban heat island mitigation strategy of increasing urban reflectivity (also known as albedo) we assumed that only roof and road surfaces would be modified. In all cases the rooftop albedo was never increased beyond 0.60 and road albedo was never increased beyond 0.30. The threshold for roof albedo of 0.6 is in line with District commercial codes that require an aged albedo of 0.55.⁵ The assumption for maximum pavement albedo of 0.3 is in line with the typical albedo of aged concrete. It is possible to achieve albedos closer to 0.7 if lighter, reflective coatings are employed. Reflective coating would typically be used on playgrounds, pedestrian walkways, or parking lots and generally not on roads, which is why we used the lower number.

Two specific scenarios were investigated. In the first, referred to as **ALB1**, the overall albedo of all urban cells was increased from 0.15 to 0.25 (an increase of 0.1) by increasing road and roof albedos. The road and roof albedos were increased by more than 0.1 to achieve the desired overall increase because urban areas also included some fraction of unbuilt/natural surfaces. The study team also simulated a higher albedo modification case, referred to as **ALB2**, for one heat event. In this case we increased the baseline albedo of all urban cells from 0.15 to 0.35 (an increase of 0.2). To incorporate the vegetation scenario, we increased the total urban vegetation fraction from roughly 10% to roughly 20% (an increase of 0.1). We included the vegetation scenario as part of a combined case in which urban area albedo was increased by 0.10 while the vegetative cover in urban areas was simultaneously increased by 0.10. The resulting simulation is referred to as **Alb1Veg1**.

3. A stepwise linear regression is a more sophisticated technique than standard linear regression. It evaluates combinations of variables that impact mortality rather than looking at them in isolation.

4. Solar energy is used by the environment in one of three ways: to heat the air, heat the ground, or to evaporate water. In general, areas tend to be cooler when more solar energy that is used to evaporate water than to heat air or surfaces.

5. District roof albedo requirements are based on a process managed by The Cool Roof Rating Council that determines aged albedos after a 3 year aging and weathering period. In practice, some roofs will outperform the 0.55 albedo requirement because they are less than 3 years old or because they are a higher performing product. Thus we allowed for a maximum albedo of 0.6 in the study.

Heat Event Selection

We developed scenarios for four separate heat events that had negative health impacts in the area:

July 18–23, 1991

June 17–22, 1994

June 21–25, 1997

July 21–26, 2010

We generally selected early-to mid-season heat waves, since much of our research indicates that the negative health outcomes from excessive heat events are greatest earlier in the season when the pool of susceptible individuals is largest (many of the people susceptible to heat death have died by the time August has arrived; Kalkstein et al., 2011). For each of these heat waves, we developed an ALB1 and Alb1Veg1 scenario. For the June 1994 heat wave, we also developed an ALB2 scenario. We compared these scenarios to the actual conditions that occurred during the heat wave and evaluated the following:

Air mass type for each day. Were there changes in air mass type from “offensive” MT+ and DT to more benign air mass types during any of the cooling scenarios?

Temperature and dewpoint temperature changes.

We determined afternoon (5:00 p.m. local time) changes in these parameters for all the scenarios. For two of the scenarios (ALB1 and Alb1Veg1 for the June, 1997 heat event), we developed maps of temperature changes for various hours in the District and surrounding areas (Appendix A).

- **Mortality changes.** We determined estimates of mortality reduction for all heat events and scenarios using the Washington mortality algorithms for the offensive air mass types. The algorithms are:

For the DT air mass:

$$Mort = -13.197 + 1.07 \times DIS - 0.066 \times TOS + 0.612 \times Atp$$

For MT+ and MT++ air masses:

$$Mort = -8.168 - 0.016 \times TOS + 0.301 \times Atp$$

- **Mort** is the estimate of the daily heat-induced mortality,
- **DIS** is the day in sequence (for example, for each consecutive day within the DT air mass, the estimated mortality increases by 1.07),

- **TOS** is time of season (for example, for each later day within the season, estimated mortality within the DT air mass decreases by 0.066), and
- **Atp** is afternoon apparent temperature, similar to the National Weather Service “heat index,” which combines the impacts of temperature and humidity.

It is clear that all the scenarios led to some decrease in temperature from actual conditions during all the heat events (See Table 4). Although the decreases weren’t dramatic, sometimes 0.5°F or less, these types of interventions can lead to significant decreases in heat-related deaths. There were some cases where reductions were around 1.0°F or greater, particularly for the ALB2 case. The Alb1Veg1 scenario showed greater temperature reductions than the ALB1 scenario, but there was a tradeoff in dewpoint temperature. In general, there were increases in dewpoint when vegetation was increased, because more vegetation transpires more water into water vapor into the atmosphere, thus increasing humidity. Similar results were noticed when developing these scenarios for other cities in previous EPA analyses (Kalkstein and Sheridan, 2005). However, apparent temperatures were generally lowest during the Alb1Veg1 scenarios, indicating that the reduction in temperature more than compensated for the increase in dewpoint. Not surprisingly, the greatest reductions in apparent temperatures occurred in the ALB2 scenario.

Changes in air mass type are more predictive than changes temperature and apparent temperature when determining the impact of the scenarios on lessening the danger of oppressive weather to residents (Table 5). If a day can be moved from an oppressive air mass, such as DT, to a relatively benign air mass, such as DM, sizable reductions in the number of heat related deaths are possible. In two of the four heat events, this type of air mass change did occur, indicating that the changes in weather conditions attributed to the increase in albedo and/or vegetation were significant.

Table 4. Temperature (T), dewpoint (Td) and apparent temperature (AT) at 5:00 p.m. local time for the four District heat events. Observed represents the actual event.

Scenario:	Observed (°F)			0.1 ↑ Albedo (°F)			Vegetation (°F)			0.2 ↑ Albedo (°F)		
Temperature Variable:	T	Td	AT	T	Td	AT	T	Td	AT	T	DT	AT
18-Jul-91	95.0	64.9	99.2	94.7	64.8	98.9	94.5	64.8	98.6	-	-	-
19-Jul-91	91.9	73.9	101.9	91.7	73.9	101.6	91.5	74.0	101.4	-	-	-
20-Jul-91	98.1	68.0	104.0	97.7	68.1	103.8	97.5	68.4	103.7	-	-	-
21-Jul-91	100.0	66.9	105.4	99.9	66.7	105.1	99.6	67.0	105.0	-	-	-
22-Jul-91	89.1	75.0	99.8	88.8	74.8	99.3	88.5	74.9	99.1	-	-	-
23-Jul-91	77.0	71.1	85.0	76.4	71.9	85.0	76.7	71.7	85.1	-	-	-
Event Average	91.9	70.0	99.2	91.5	70.0	99.0	91.4	70.1	98.8			
17-Jun-94	89.1	73.0	98.4	88.8	73.2	98.2	88.6	73.3	98.1	89.6	70.4	97.1
18-Jun-94	93.0	68.0	99.0	92.7	68.0	98.7	92.2	68.2	98.3	91.7	68.5	98.0
19-Jun-94	96.1	73.0	105.4	96.5	71.7	104.9	96.3	72.6	105.3	96.2	73.0	105.5
20-Jun-94	91.0	69.1	97.7	90.8	69.0	97.4	90.5	68.8	97.0	90.3	69.0	97.0
21-Jun-94	90.0	75.0	100.7	89.8	75.0	100.5	89.5	74.9	100.1	89.4	75.1	100.1
22-Jun-94	93.0	60.1	94.7	92.7	60.3	94.4	92.4	60.6	94.3	92.2	60.7	94.1
Event Average	92.0	69.7	99.3	91.9	69.5	99.0	91.6	69.7	98.9	91.6	69.4	98.6
21-Jun-97	83.5	72.1	92.2	82.1	72.0	90.7	83.3	72.1	92.0	-	-	-
22-Jun-97	82.6	71.6	90.4	82.2	71.4	90.4	82.3	71.1	90.3	-	-	-
23-Jun-97	78.6	62.2	81.2	78.2	62.5	81.2	78.0	62.4	80.9	-	-	-
24-Jun-97	81.5	70.3	88.7	81.2	70.3	88.7	81.5	70.2	88.9	-	-	-
25-Jun-97	84.2	75.4	95.4	83.9	76.1	95.4	84.0	75.6	95.2	-	-	-
Event Average	82.1	70.3	89.6	81.5	70.5	89.3	81.8	70.3	89.5			
21-Jul-10	91.9	57.9	92.6	91.5	58.0	92.2	91.2	58.2	92.0	-	-	-
22-Jul-10	96.1	66.9	101.4	96.4	66.6	101.6	94.9	67.5	100.6	-	-	-
23-Jul-10	96.1	69.1	102.7	95.7	69.2	102.4	95.4	70.0	102.7	-	-	-
24-Jul-10	95.0	68.0	101.0	94.6	68.4	100.9	94.5	68.6	100.9	-	-	-
25-Jul-10	91.0	62.1	93.7	90.4	63.0	93.6	90.1	63.7	93.7	-	-	-
26-Jul-10	93.0	62.1	95.7	91.7	64.1	95.4	91.5	64.1	95.3	-	-	-
Event Average	94.2	65.6	98.9	93.8	66.3	98.8	93.3	66.8	98.6			

Table 5. Air mass type on each of the days during the heat event. Darkened air mass types indicate scenario-induced changes from the observed conditions.

Air Masses				
Scenario	Observed	Alb1	Alb1Veg1	Alb2
18-Jul-91	DT	DT	DT	-
19-Jul-91	MT+	MT+	MT+	-
20-Jul-91	DT	DT	DT	-
21-Jul-91	DT	DT	DT	-
22-Jul-91	MT+	MT+	MT+	-
23-Jul-91	DT	DT	DT	-
17-Jun-94	MT++	MT+	MT+	MT+
18-Jun-94	MT++	MT+	MT+	MT+
19-Jun-94	MT++	MT++	MT++	MT++
20-Jun-94	MT++	MT+	MT+	MT+
21-Jun-94	MT+	MT+	MT+	MT+
22-Jun-94	DT	DT	DT	DT
21-Jun-97	MT+	MT+	MT+	-
22-Jun-97	MT++	MT+	MT+	-
23-Jun-97	DT	DT	DT	-
24-Jun-97	DT	DM	DM	-
25-Jun-97	DT	DT	DT	-
21-Jul-10	DT	DT	DT	-
22-Jul-10	MT+	MT+	MT+	-
23-Jul-10	DT	DT	DT	-
24-Jul-10	DT	DT	DT	-
25-Jul-10	DT	DT	DT	-
26-Jul-10	DT	DT	DT	-

During the June 1994 and June 1997 events, days shifted from more oppressive air mass types to less oppressive types. On three days of the June 1994 event, MT++ air mass days were improved to MT+ air masses; on one day during the June 1997 event, this occurred as well. June 24, 1997 experienced the most pronounced change—a very oppressive DT day was transformed to a DM day for both the ALB1 and Alb1Veg1 scenarios. Such changes can lead to substantial reductions in mortality during heat events (the changes could also lead to significant health improvements, though that was outside the scope of this study).

Two of the four heat events showed air mass changes from more to less oppressive conditions. This 50% ratio is similar to what we found in our EPA-funded studies (Kalkstein and Sheridan, 2005), although the number of days when air mass changes occurred during the four heat events (5 out of 23 total days, or 22 percent of days) is higher than what we determined for cities we evaluated in the EPA study.

The impact of these scenarios on mortality varied from one heat event to the next (Table 6). The largest reductions occurred during those events when there were actual air mass changes, particularly the June 1997 heat wave, when a DT day was altered to a DM day during the ALB1 and Alb1Veg1 scenarios. DM is a totally benign air mass type, which led to 0 excess deaths on 24 June 1997, when this air mass transformation occurred. When summing all the events together, estimates show roughly 45 total heat-related deaths. Under the ALB1 scenario, the combined total was reduced to 42 deaths, and this number dropped to 41.6 deaths under the Alb1Veg1 scenario. Considering the relatively large number of heat-related deaths in the District over a long time span of heat events, the number of lives saved is significant.

The research team mapped the District and surrounding regions to determine when and where the greatest temperature reductions would take place under the ALB1 and Alb1Veg1 scenarios for June 20, 1997 (Figures 2 and 3 are an example; full mapping of the two scenarios is found in Appendix A). The maps show temperature differentials from the actual conditions on that day. It is noteworthy that the greatest differentials occur in the northeastern and southeastern sections of the city, where some of lowest-income areas of the District exist. Thus, the ALB1 case indicates that the greatest temperature reductions would occur in one of the sections of the city where the population that is most vulnerable to heat-related health problems is found.⁶

For the entire day of June 20, the greatest cooling occurs from mid-morning into the afternoon. There is a slight generalized cooling overnight, but the darker blue areas are apparent during the daylight hours. This occurred for both scenarios. During the warmest part of the day, there is a narrow strip of warming (red area) to the north and east of the city, just on the landward side of the Chesapeake Bay. Also noticeable is a wind shift at the site of the warming, mainly from the west on the landward side and from the south on the eastern side. This suggests a reduction of the sea breeze in this very localized area. The sea breeze occurs when the contrasting hot temperatures over land and relatively cool temperatures over the water cause a flow from the bay to the land, where hot air is more buoyant and rises. If we cool the land to some degree, the sea breeze is diminished over a very narrow strip just adjacent to the water, since the temperature differential between land and water is decreased. The result is a warming strip adjacent to where the sea breeze is diminished. It is most pronounced during the warmest part of the day, from late morning to mid afternoon, as demonstrated in Appendix A. Similar results were obtained when we developed scenarios for Baltimore. Areas that experienced this localized warming were more suburban/rural in nature and remained cooler than the city despite the reduction in sea breeze.

6. Per Jesdale et al 2013. District-specific poverty and demographic data compiled in the Urban Institute National Data Repository. Mapping accessed at http://www.metrotrends.org/spotlight/Washington_poverty.cfm.

Table 6. Estimated mortality for days within the evaluated heat events.

Mortality Estimates				
Scenario	Observed	Alb1	Alb1Veg1	Alb2
18-Jul-91	1.7	1.7	1.6	-
19-Jul-91	2.0	1.9	1.9	-
20-Jul-91	2.2	2.1	2.1	-
21-Jul-91	2.3	2.3	2.2	-
22-Jul-91	1.7	1.7	1.6	-
23-Jul-91	0.2	0.2	0.2	-
Event Total	10.1	9.9	9.6	-
17-Jun-94	2.1	2.1	2.1	2.0
18-Jun-94	2.1	2.1	2.1	2.0
19-Jun-94	2.8	2.7	2.7	2.8
20-Jun-94	2.0	1.9	1.9	1.9
21-Jun-94	2.3	2.2	2.2	2.2
22-Jun-94	1.6	1.6	1.6	1.6
Event Total	12.9	12.6	12.6	12.4
21-Jun-97	2.2	2.2	2.1	-
22-Jun-97	2.2	2.2	2.2	-
23-Jun-97	1.2	1.2	1.2	-
24-Jun-97	2.1	0.0	0.0	-
25-Jun-97	2.5	2.4	2.5	-
Event Total	10.2	8.0	8.0	-
21-Jul-10	1.4	1.4	1.4	-
22-Jul-10	2.3	2.3	2.2	-
23-Jul-10	2.4	2.4	2.4	-
24-Jul-10	2.2	2.2	2.2	-
25-Jul-10	1.5	1.5	1.5	-
26-Jul-10	1.7	1.6	1.6	-
Event Total	11.6	11.5	11.4	-
GRAND TOTAL	44.8	42	41.6	
<i>% Reduction</i>		6.2%	7.1%	

Figure 2. Temperature reductions using the ALB1 scenario on June 20, 1997, at 9:00 a.m.
Maps for the entire day are found in Appendix A.

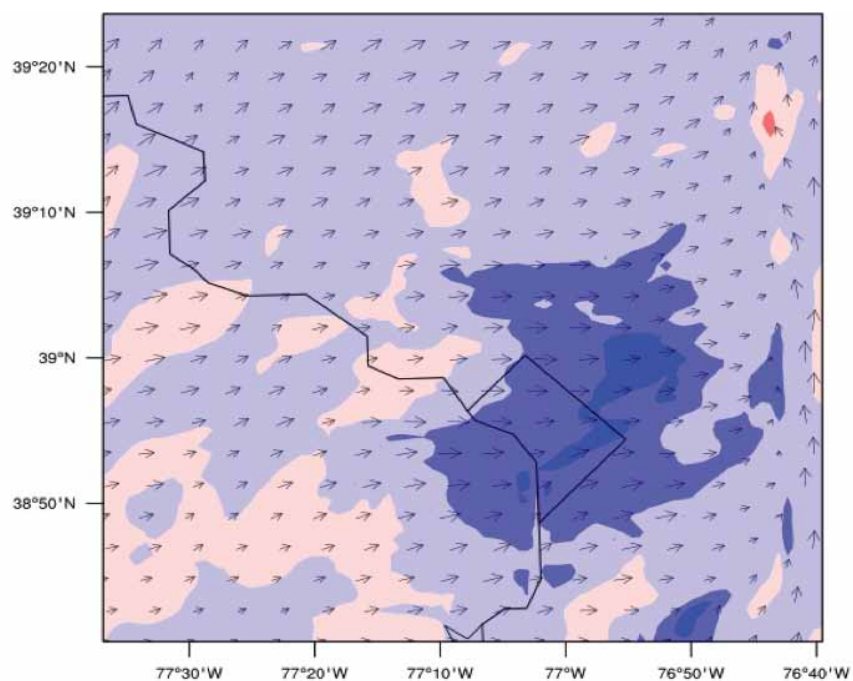
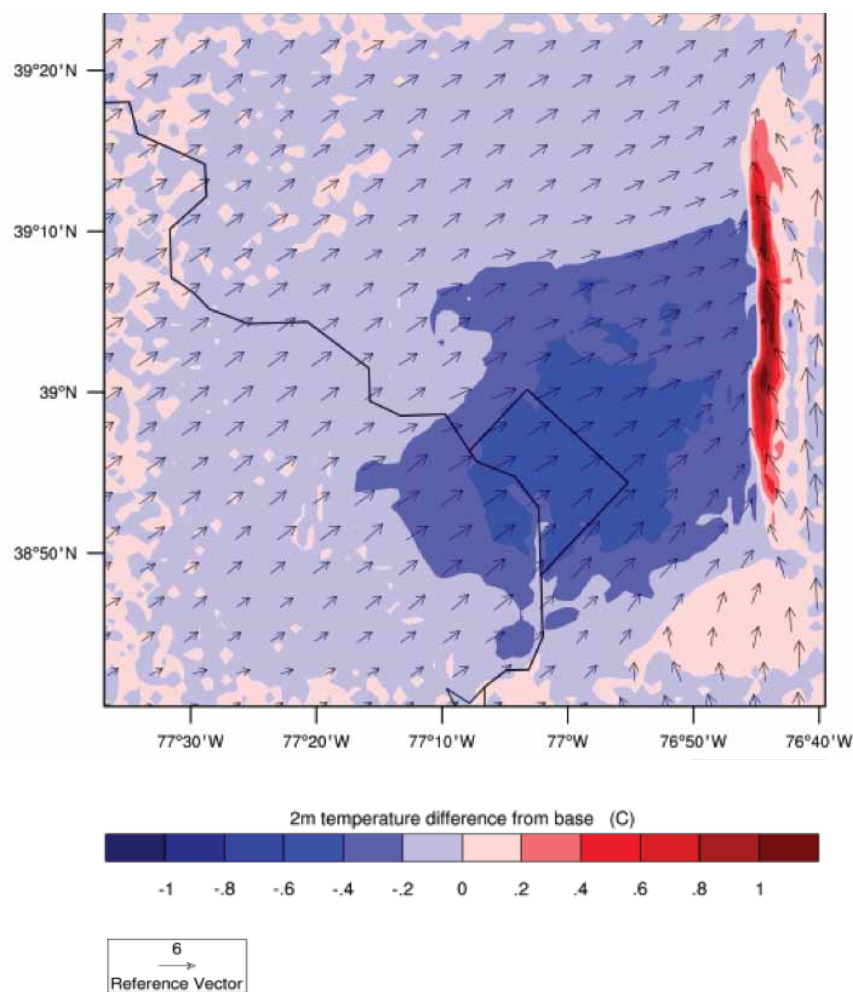


Figure 3. Temperature reductions using the Alb1Veg1 scenario on June 20, 1997, at 11:00 a.m.
Maps for the entire day are found in Appendix A.



RECOMMENDATIONS AND CONCLUSIONS

The results reveal that altering the landscape of Washington in a manner that increases albedo and vegetation will lead to some cooling of the urban area, particularly in the sections of the city where the most vulnerable people reside. In addition, there is sufficient cooling in two of the four evaluated heat events to shift days into less oppressive air masses. This shift contributes to the 7% reduction in heat-related mortality totals. Based on our previous work, approximately 285 people die of heat-related causes during an average decade in the District (Kalkstein et al., 2011), when 11% of summer days experience oppressive air masses. A 7% reduction brings this number to 265, meaning that 20 lives could be saved during a decade using UHI reduction strategies. This is a conservative estimate; given that closer to 18% of summer days experienced oppressive air masses during the last decade.

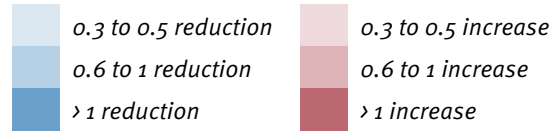
In general, the Alb1Veg1 showed levels of cooling somewhat greater than the ALB1 scenario alone (Table 7), and the greatest cooling, more than 1°F, occurred during the July, 2010, heat wave during the Alb1Veg1 scenario. However, this was accompanied by an increase in dewpoint, and thus atmospheric water vapor, which led to apparent temperature reductions similar to the ALB1 scenario. But there was also a slightly greater mortality decrease under the Alb1Veg1 scenario that may render it better in terms of improving urban heat conditions versus the ALB1 scenario. The greatest

apparent temperature decreases occurred under ALB2 conditions, which were only evaluated during the June 1994 heat event. In the long run, urban modifications that would allow for ALB2 conditions would likely lead to even more lives being saved, although the cost/benefit of such modifications would need further evaluation.

These results are somewhat similar to those obtained in earlier EPA-funded studies on cool cities, and also resemble results using these models in Baltimore. The susceptibility seems higher in Baltimore than in Washington; for our evaluated four heat waves there, we determined that about 124 heat-related deaths occurred, and under a similar Alb1Veg1 scenario that was used for Washington, this total dropped to approximately 117 (Kalkstein et al., in preparation).

While it appears unlikely that urban heat island mitigation technologies, such as the ones discussed in this evaluation, will contribute to large urban-scale reductions in temperature during heat events (such as 5°F or greater), the study demonstrates that cooling temperatures a single degree for much of a day can lead to an air mass category change, and during some intense heat waves, this results in reductions in mortality.

Table 7. Temperature changes (Scenario-Observed, °F) from actual conditions under each of the scenarios.



Scenario	Alb1 (°F)			Alb1Veg1 (°F)			Alb2 (°F)		
	T	Td	AT	T	Td	AT	T	Td	AT
18-Jul-91	-0.3	-0.1	-0.3	-0.5	-0.1	-0.6	-	-	-
19-Jul-91	-0.2	0.0	-0.2	-0.5	0.0	-0.5	-	-	-
20-Jul-91	-0.3	0.1	-0.3	-0.6	0.4	-0.3	-	-	-
21-Jul-91	-0.1	-0.2	-0.2	-0.4	0.0	-0.4	-	-	-
22-Jul-91	-0.3	-0.2	-0.4	-0.6	-0.1	-0.7	-	-	-
23-Jul-91	-0.6	0.8	-0.1	-0.3	0.7	0.1	-	-	-
Average	-0.3	0.1	-0.3	-0.5	0.1	-0.4	-	-	-
17-Jun-94	-0.3	0.1	-0.2	-0.5	0.3	-0.3	0.5	-2.6	-1.3
18-Jun-94	-0.4	0.0	-0.4	-0.8	0.2	-0.7	-1.3	0.5	-1.0
19-Jun-94	0.4	-1.3	-0.5	0.2	-0.4	-0.1	0.2	0.0	0.1
20-Jun-94	-0.2	-0.1	-0.3	-0.5	-0.3	-0.7	-0.7	-0.1	-0.7
21-Jun-94	-0.2	0.0	-0.2	-0.5	-0.2	-0.6	-0.6	0.1	-0.5
22-Jun-94	-0.4	0.2	-0.3	-0.7	0.5	-0.4	-0.8	0.6	-0.6
Average	-0.2	-0.2	-0.3	-0.5	0.0	-0.5	-0.5	-0.3	-0.7
21-Jun-97	-0.1	0.8	0.4	-0.5	0.0	-0.5	-	-	-
22-Jun-97	0.1	0.1	0.1	-0.3	-0.1	-0.4	-	-	-
23-Jun-97	-0.3	0.3	-0.2	-0.6	0.4	-0.4	-	-	-
24-Jun-97	-0.2	-0.1	-0.2	-0.6	0.1	-0.5	-	-	-
25-Jun-97	0.2	-2.8	-1.4	-0.6	0.2	-0.5	-	-	-
Average	-0.1	-0.3	-0.3	-0.5	0.1	-0.5	-	-	-
21-Jul-10	-0.4	0.1	-0.4	-0.8	0.3	-0.6	-	-	-
22-Jul-10	0.3	-0.3	0.2	-1.2	0.6	-0.8	-	-	-
23-Jul-10	-0.4	0.1	-0.3	-0.6	0.9	-0.1	-	-	-
24-Jul-10	-0.4	0.4	-0.1	-0.5	0.6	-0.1	-	-	-
25-Jul-10	-0.6	0.9	-0.1	-0.9	1.7	0.0	-	-	-
26-Jul-10	-1.4	2.1	-0.3	-1.5	2.0	-0.4	-	-	-
Average	-0.47	0.56	-0.17	-0.92	1.00	-0.35	-	-	-

District Policies to Mitigate Urban Heat Islands

The Government of the District of Columbia has recognized the cross-cutting problem of excess heat and has promoted reflective surface and increased vegetative cover installations through a number of policy vehicles.

The District's Sustainable DC Plan, finalized in February 2013, notes the importance of installing reflective and vegetated roofs for reducing greenhouse gas emissions and for their heat island mitigating benefits, and the District remains one of the leading cities in the nation for vegetated roof installation, with more than 130 green roofs covering more than 1.5 million square feet. The District Department of the Environment's ("DDOE") RiverSmart Program has contributed to reducing the UHI effect by increasing the permeability of 5,500 single-family home sites with rain gardens, shade trees, and vegetated roofs.

DDOE recently finalized stormwater regulations that require 1.2 inches of stormwater management for new construction and substantial improvement projects of certain sizes. The regulations require a certain amount of stormwater to be retained on site, but also allows for an innovative Stormwater Retention Credit trading program for off-site mitigation. The program could significantly boost vegetative cover throughout the District and contribute to reductions in excess urban heat. The District also has a long-standing tree canopy restoration program that has added 810 acres of tree canopy, or 2% of total urban area, since 2006. The District also instituted a Green Area Ratio (GAR) site sustainability metric, effective October 1, 2013. The GAR is a zoning measure that sets standards for landscape and site design elements, such as vegetated roofs, that help manage stormwater runoff, improve air quality, and reduce the urban heat island effect.

The District's Department of General Services' (public buildings division) Smart Roof Program is a comprehensive assessment of 11 million square feet of District-owned properties to determine the structural and economic feasibility of a variety of cool and efficient roof types including vegetated, reflective, blue, and solar energy applications. The program will include retrofits of up to 3 million square feet of District-owned roofs and is anticipating a three-year payback for most projects. The District's Climate Adaptation and Resiliency Plan received funding in December 2012 and is currently in development. Excess heat is one of the priority issues that the plan is seeking to address.

Cool roof standards for commercial buildings have been in DC Energy Conservation Code since 2008. The proposed 2013 codes for the District include additional cool roof requirements for both the commercial and residential sectors. The proposed codes also include the adoption of a Green Construction Code, which include provisions for more reflective site hardscapes, shading, and pervious/permeable pavements.

The Green Building Act of 2006 requires LEED certification, which includes points for cool and vegetated roofs, for private buildings larger than 50,000 square feet and all public and publically financed commercial projects. Residential projects that involve at least 15% of public financing are required by the Act to meet the Enterprise Green Communities criteria, which also include cool and green roof provisions.

With these programs, it is possible that urban temperatures or dewpoints can be altered significantly to the point that a day which might have been within an oppressive air mass will now be within a non-oppressive air mass. ACI's research has shown that a change of only a few degrees in temperature might save a significant number of lives (Kalkstein and Sheridan, 2005). In addition, it is clear that reductions in nighttime temperature are at least as important in mitigating heat-related health problems as similar reductions during the daytime (Greene et al., 2011).

Policy Recommendations

The District is a national leader on urban heat island mitigation policies and programs. The District should continue to focus on enforcement and implementation of the existing slate of policies and programs. The following recommendations could further enhance District policies to reduce excess heat.

1. Encourage Regional Collaboration

As the scenario mapping indicates, mitigating excess urban heat has regional impacts. The District region often experiences winds out of the southwest during high heat days so Northern Virginia cooling strategies will have effects in the District and District cooling strategies will affect Prince George's County. The District could recognize this interconnectivity by opening a dialogue within the Metropolitan Washington Council of Governments to collaborate on a shared strategic vision for regional heat mitigation.

2. Undertake Additional Research

An evaluation of health impacts was not in the scope of this study. The District could expand this study by incorporating negative health impacts resulting from heat and air quality deterioration. Doing so would significantly aid District efforts to understand its specific heat challenges and to prioritize where and how to intervene during heat events. The District could refine the demographic impacts briefly described in this report. A further extension of this study would be to estimate the economic impact on the District of premature mortality and other health impacts due to excess heat.

3. Raise Public Awareness

The District could launch a marketing campaign to help residents understand the benefits of installing reflective roofs and expanding vegetated areas. Similar programs in New York City and Philadelphia have been successful in improving the public's understanding of their role in reducing excess urban heat. New York City operates a volunteer program to coat roofs on appropriate public housing and non-profit buildings. The program is supported by skilled labor provided primarily by disadvantaged youth who have completed a training program run by a local non-profit. New York City also ran advertisements in selected bus shelters to explain urban heat islands and cool roofs. Philadelphia undertook a "Coolest Block" contest where individual residential blocks competed to have a cool coating applied to their home. As part of the selection process, the blocks had to achieve a critical mass of willing homeowners and explain why they wanted to be a "cool block." Both programs could be modified to work successfully in the District to raise public awareness.

4. Create a "Cool Zone"

The District could work with community, industry, and academic stakeholders to create a geographically contiguous "cool zone" where they can deploy (or encourage installment of) urban heat island mitigation technologies in close proximity. The cool zone could be fully instrumented to empirically measure the impact on meteorological conditions of reflective roofs, vegetated roofs, cool pavements and additional vegetation. It would also provide an opportunity to evaluate social benefits and impacts on residents in areas where urban heat island strategies are densely installed. Alternatively, the District could engage with Business Improvement Districts to create the cool zone in a commercial area.

REFERENCES

Akbari, H. Rosenfeld, A., & Menon, S., (2009). Global cooling: Increasing world-wide urban albedos to offset CO₂. *Climatic Change* 94 (3-4), 275-286.

Centers for Disease Control, 2012. Deaths and Mortality. <http://www.cdc.gov/nchs/fastats/deaths.htm>

Greene, J.S., L.S. Kalkstein, D. Mills, and J. Samenow, 2011. Performance of U.S. Cities in reducing excess mortality from extreme heat events: 1975-2004. *Weather, Climate, and Society* 3: 281-292.

Jesdale, BM et al. (2013) The Racial/Ethnic Distribution of Heat Risk-Related Land Cover in Relation to Residential Segregation. *Environmental Health Perspectives*. DOI: 10.1289/ehp.1205919

Kalkstein, L.S, Greene, J.S., D. Mills, and J. Samenow, 2011. An Evaluation of the Progress in Reducing Heat-Related Human Mortality in Major U.S. cities. *Natural Hazards* 56:113-129.

Kalkstein, L.S. and S.C. Sheridan, 2005. The Impact of Heat Island Reduction Strategies on Health-Debilitating Oppressive Air Masses in Urban Areas. Phase 1. U.S. EPA Heat Island Reduction Initiative, 26pp.

Kurn, D., S. Bretz, B. Huang, and H. Akbari. 1994. The Potential for Reducing Urban Air Temperatures and Energy Consumption through Vegetative Cooling. ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy. Pacific Grove, CA.

National Environmental Satellite, Data, and Information Service, 2012. TD-3280 Surface Airways and Airways Solar Radiation Hourly. Washington, DC, U.S. Department of Commerce.

Sheridan, S.C., 2002. The Redevelopment of a Weather Type Classification Scheme for North America. *International Journal of Climatology* 22:51-68.

Sheridan, S.C., 2013. The Spatial Synoptic Classification. <http://sheridan.geog.kent.edu/ssc.html>

APPENDIX A

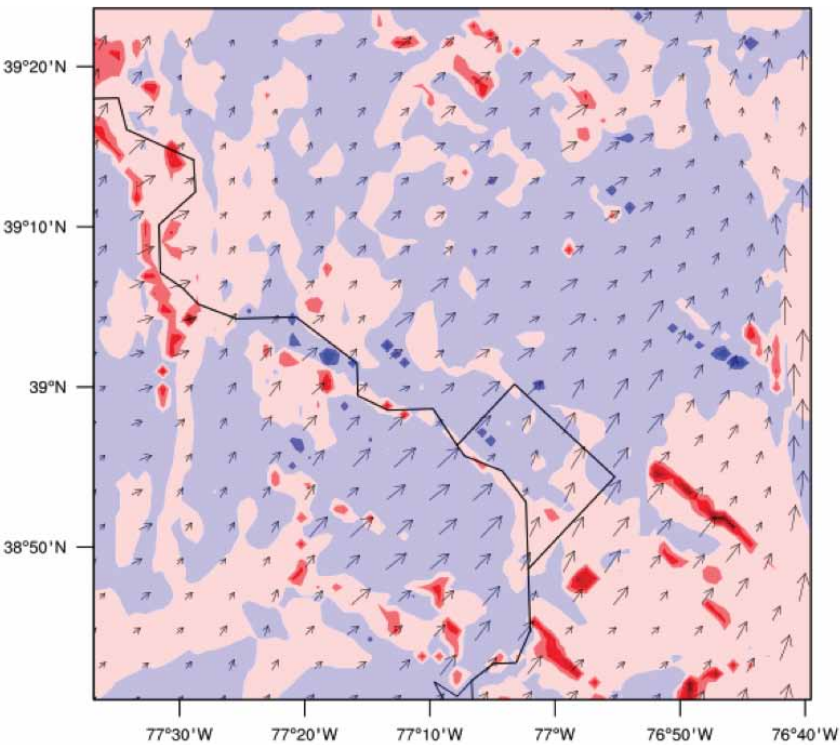
Maps of Temperature Change Resulting from Increasing Reflectivity and Vegetation in the District

We have done a complete mapping of temperature changes and wind flow for June 20, 1997, during a 12-hour period, 5:00 a.m. to 5:00 p.m. Two of the scenarios were mapped for that day, ALB1 and Alb1Veg1. Results show that the greatest cooling occurs from mid-morning to early afternoon. For more discussion on these results, please refer to the main text.

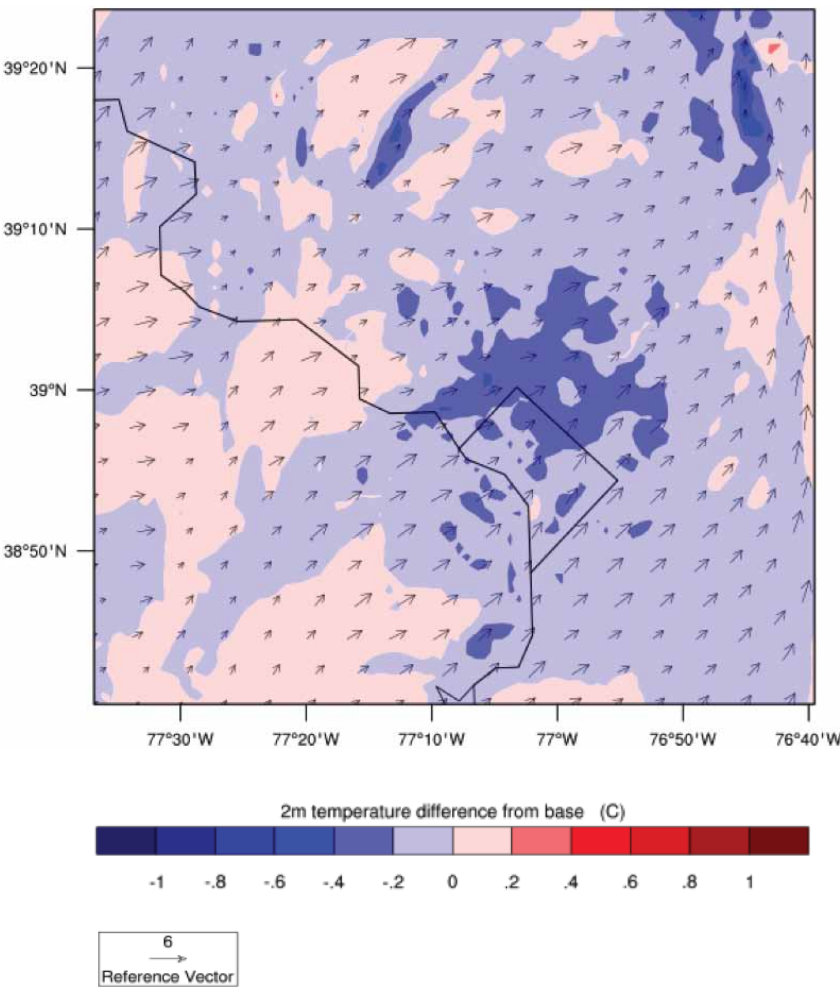
Temperature reductions using:

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- Alb1 scenario on June 20, 1997, at 7:00 a.m.
- Alb1 scenario on June 20, 1997, at 9:00 a.m.
- Alb1 scenario on June 20, 1997, at 11:00 a.m.
- Alb1 scenario on June 20, 1997, at 1:00 p.m.
- Alb1 scenario on June 20, 1997, at 3:00 p.m.
- Alb1 scenario on June 20, 1997, at 5:00 p.m.
- Alb1Veg1 scenario on June 20, 1997, at 5:00 a.m.
- Alb1Veg1 scenario on June 20, 1997, at 7:00 a.m.
- Alb1Veg1 scenario on June 20, 1997, at 9:00 a.m.
- Alb1Veg1 scenario on June 20, 1997, at 11:00 a.m.
- Alb1Veg1 scenario on June 20, 1997, at 1:00 p.m.
- Alb1Veg1 scenario on June 20, 1997, at 3:00 p.m.
- Alb1Veg1 scenario on June 20, 1997, at 5:00 p.m.

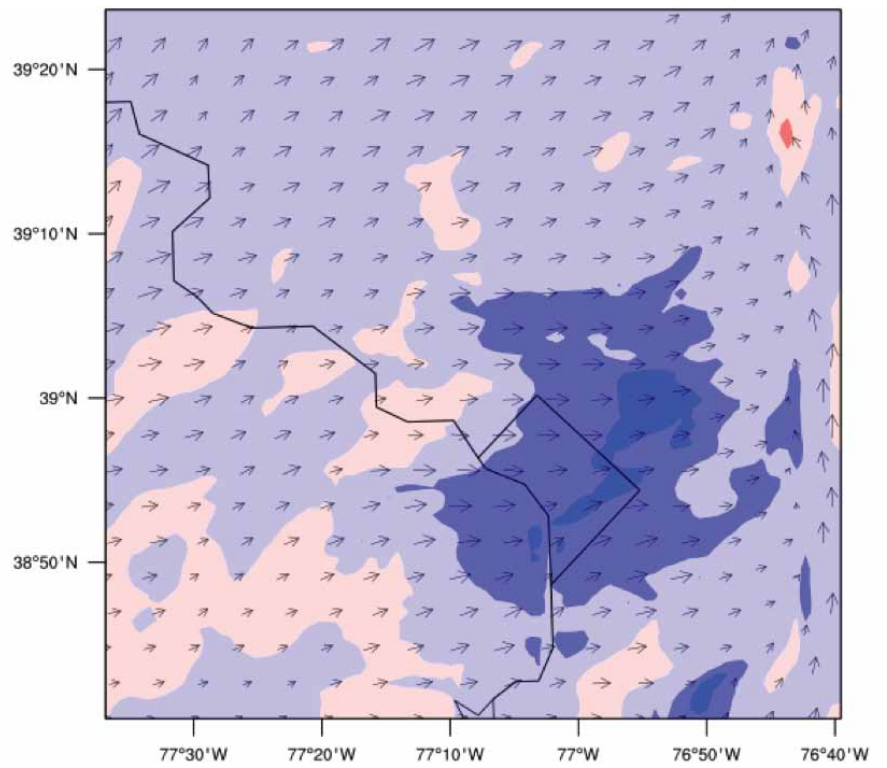
Temperature reductions
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June 20, 1997, at 5:00 a.m.



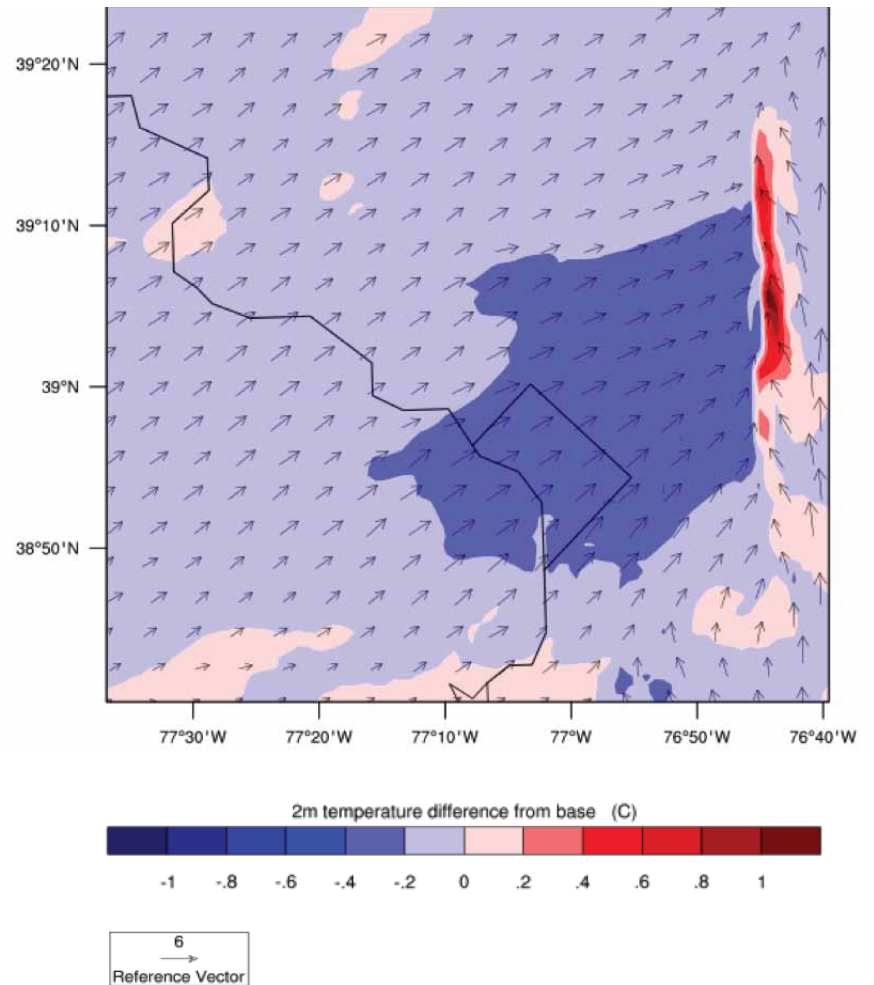
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June 20, 1997, at 7:00 a.m.



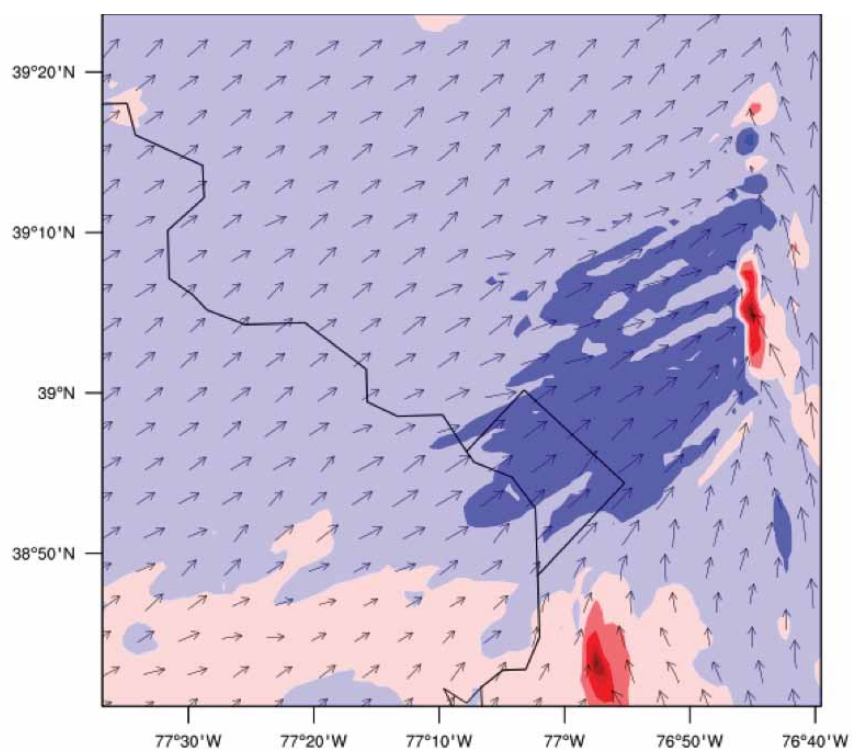
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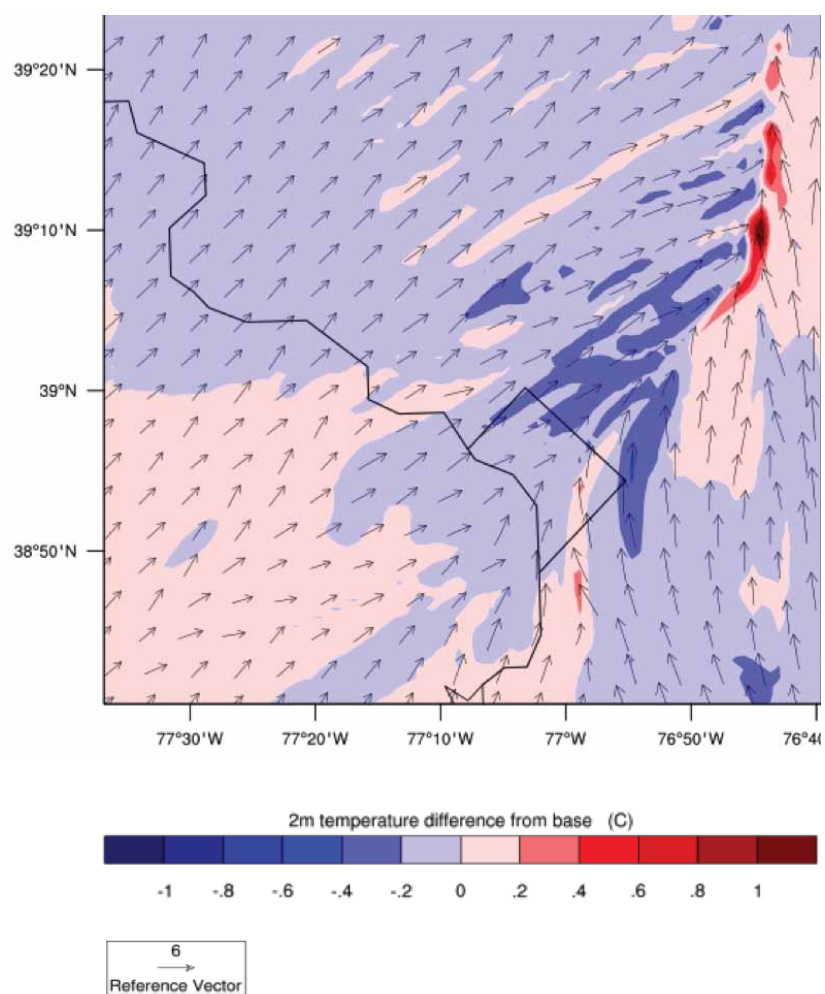
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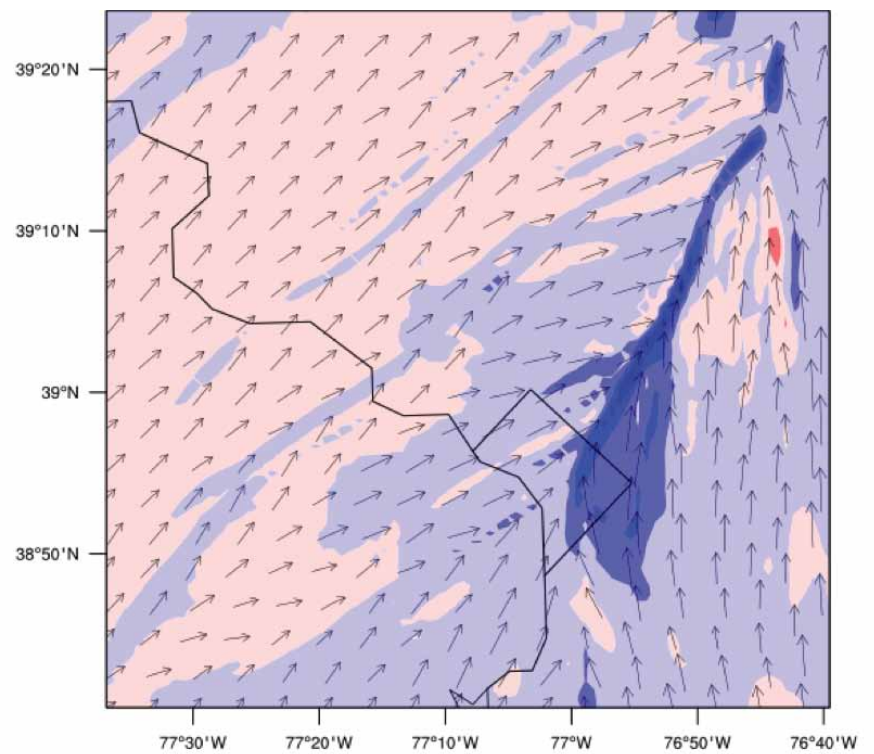
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using the Alb1 scenario on
June 20, 1997, at 1:00 p.m.**



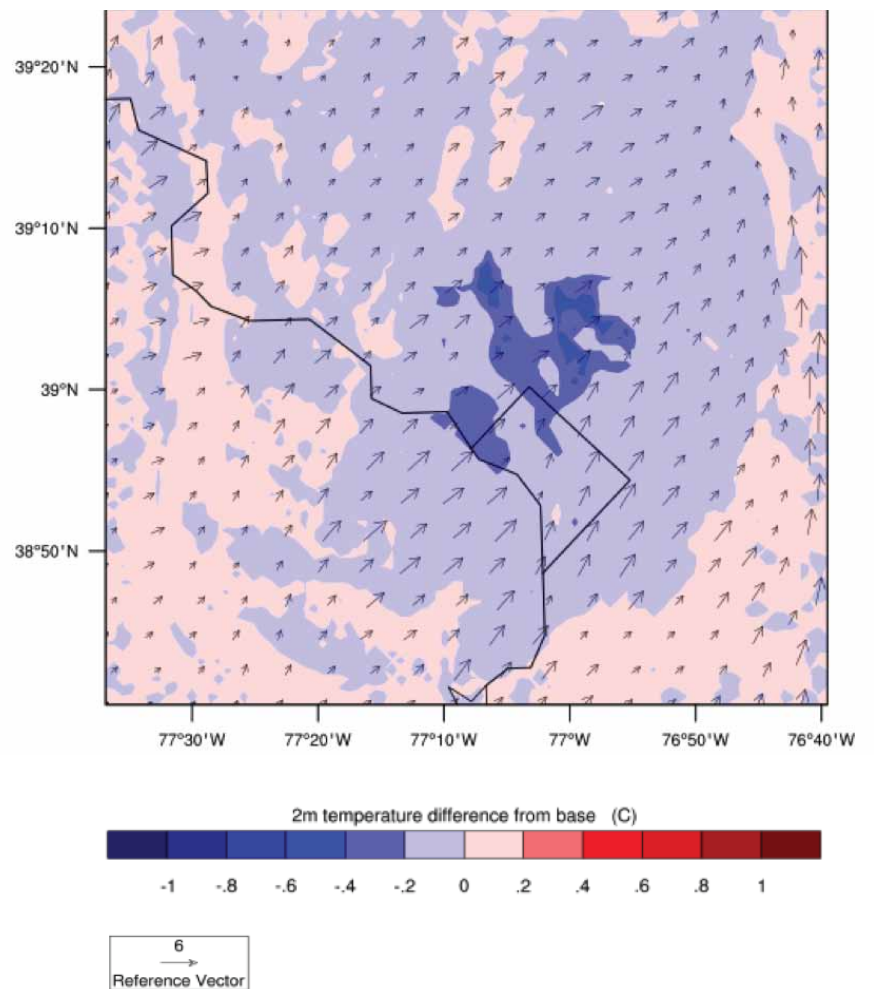
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June 20, 1997, at 3:00 p.m.**



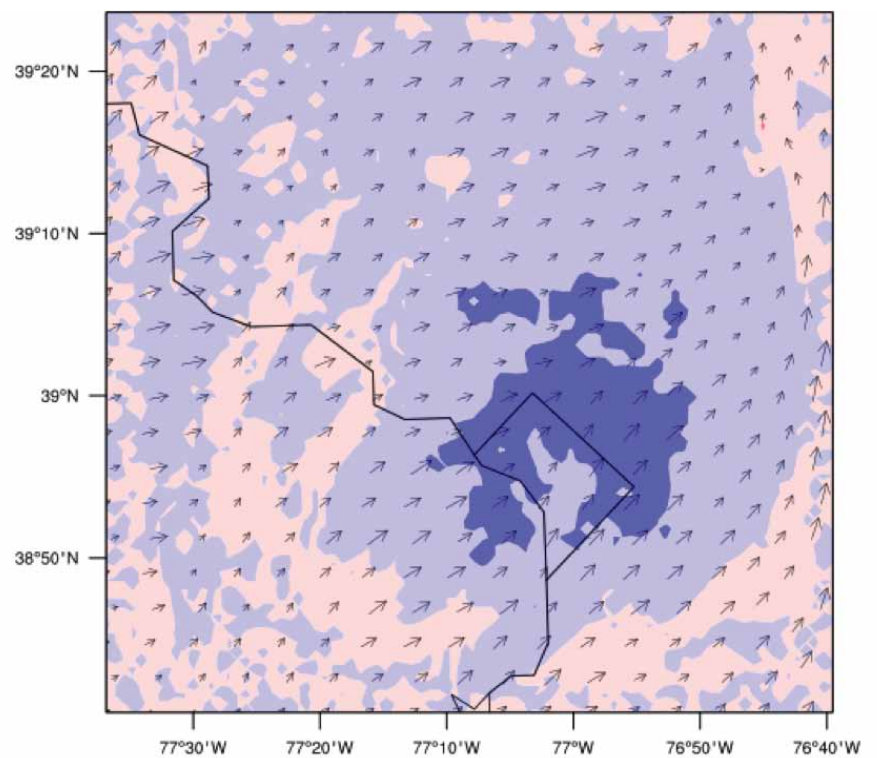
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using the Alb₁ scenario on
June 20, 1997, at 5:00 p.m.**



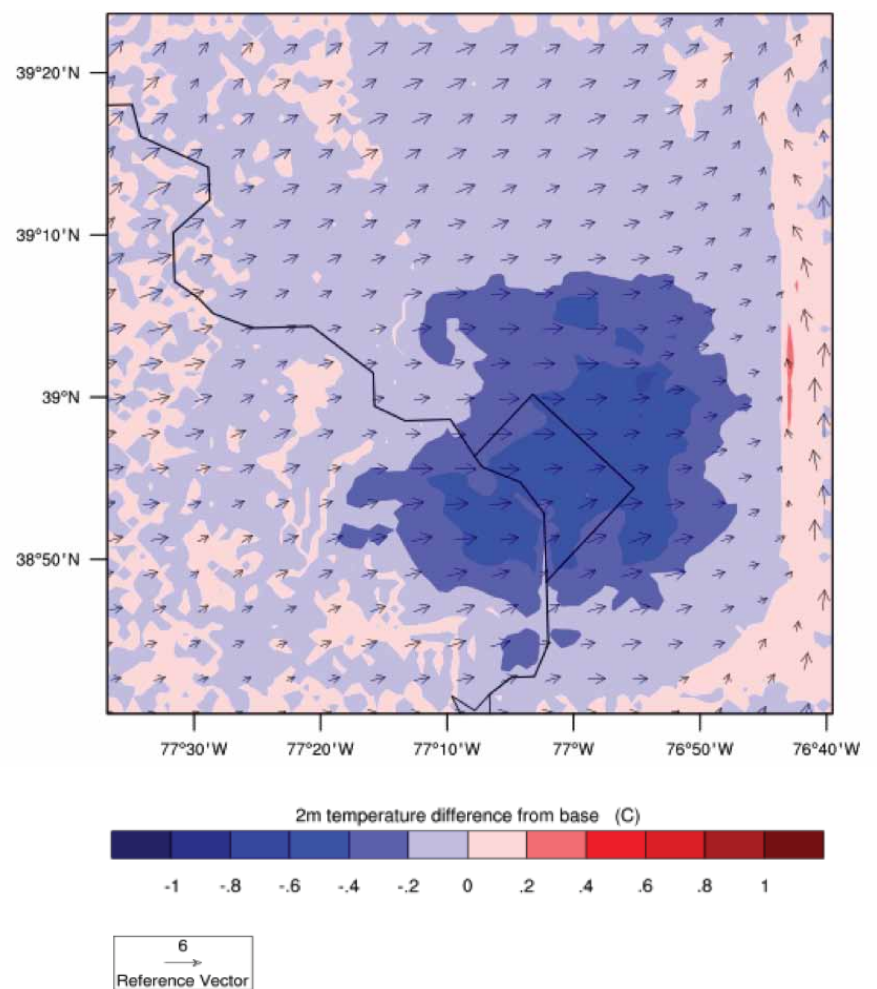
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scenario on June 20, 1997,
at 5:00 a.m.**



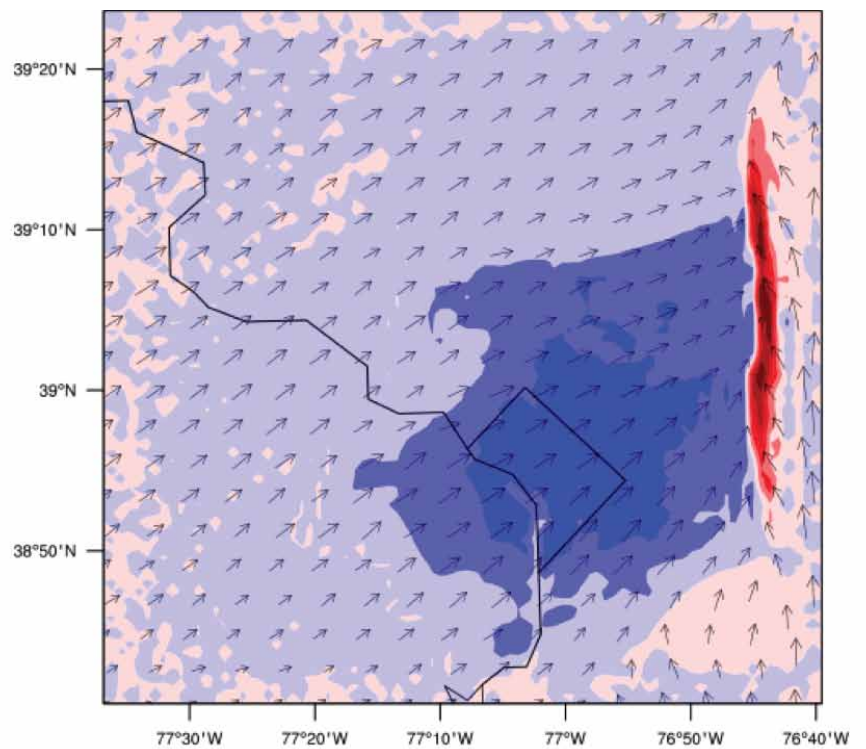
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scenario on June 20, 1997,
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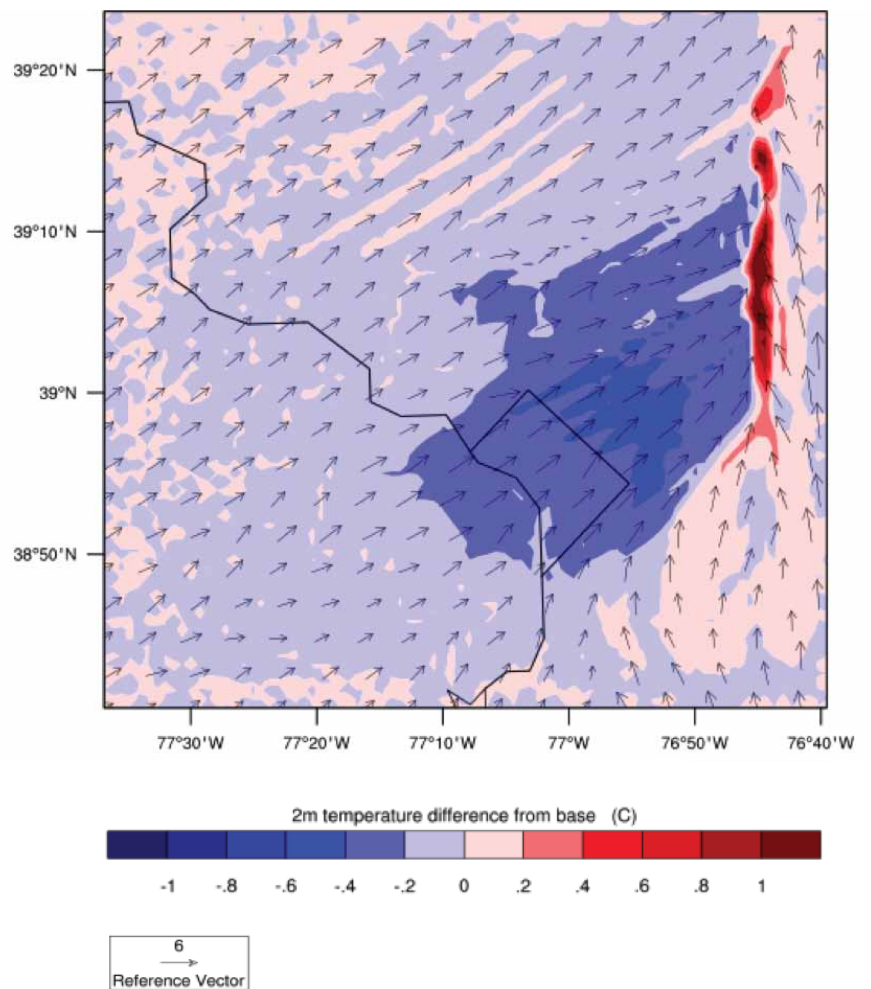
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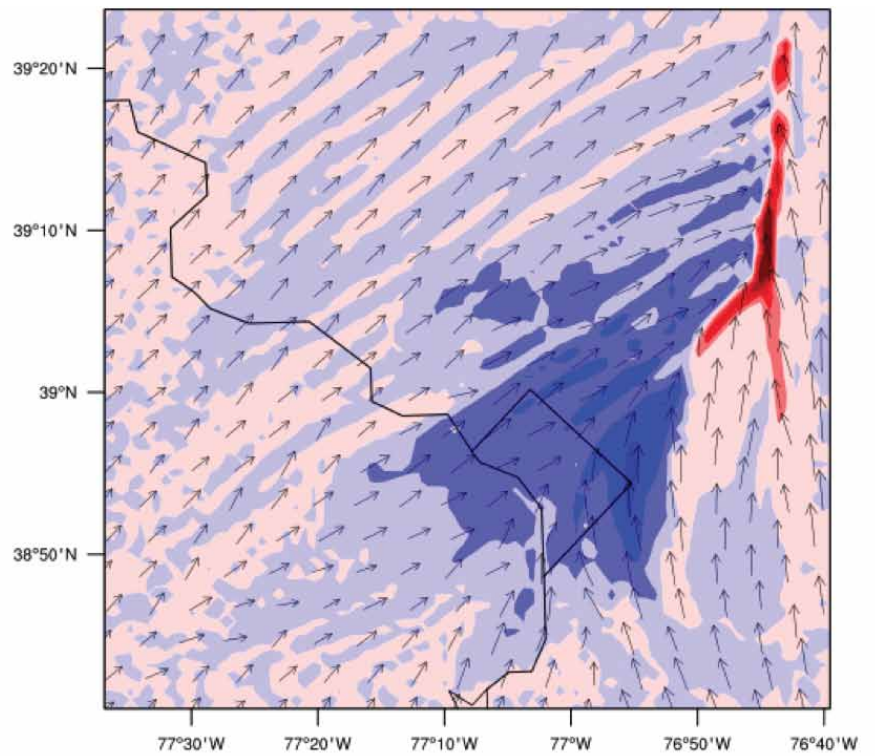
**Temperature reductions
using the Alb1Veg1
scenario on June 20, 1997,
at 11:00 a.m.**



**Temperature reductions
using the Alb1Veg1
scenario on June 20, 1997,
at 1:00 p.m.**



Temperature reductions
using the Alb1Veg1
scenario on June 20, 1997,
at 3:00 p.m.



Temperature reductions
using the Alb1Veg1
scenario on June 20, 1997,
at 5:00 p.m.

