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Rx for Hot Cities: Building Climate Resilience Through Urban Greening and Cooling in Los Angeles, California, USA

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Abstract

Extreme heat and its health impacts are on the rise. Globally, the six warmest years on record all occurred since 2015, and in Los Angeles (LA) average temperatures are expected to increase up to 4.5°C in coming decades. Extreme heat causes more deaths in the United States than all other weather-related causes combined, with heat risk being most pronounced in urban areas due to the heat-island effect. Reducing urban heat exposure is an equity issue, as low-income communities and communities of color are more likely to live in neighborhoods with older buildings, low tree canopy cover, more heat-retaining surfaces, and limited access to coping strategies such as air conditioning.

The Los Angeles Urban Cooling Collaborative (LAUCC) is a multi-disciplinary partnership of researchers and expert practitioners working with communities and government to understand and mitigate heat in LA. LAUCC completed a modeling study of current and projected heat in LA County to: 1) identify geographic areas with highest vulnerability to heat-related death; 2) quantify how various urban forest cover (UFC) and built environment albedo scenarios would affect heat-related mortality, temperature, humidity, and oppressive air masses that lead to elevated mortality; and 3) quantify the number of years that climate change-induced warming could be delayed by implementing these interventions.

We find that increasing shade, evaporative cooling, and albedo through increases in UFC and reflective surfaces could save one in four lives lost to heat waves in Los Angeles, mostly in low-income communities and communities of color. We also find that these measures could modify local meteorology sufficiently to delay local effects of global climate change-induced warming by 25 to 60 years under business-as-usual and moderate mitigation scenarios, respectively. These strategies can be adapted to combat extreme heat in other regions that are experiencing similar challenges.

Keywords: Human health and well-being, Research, Sustainable forest management, Adaptive and integrated management, Climate change

Introduction, scope and main objectives

Extreme heat threatens public health

Extreme heat has negative health consequences including increases in emergency room visits, hospitalizations, and premature deaths. Heat kills more people than hurricanes, floods, tornadoes and lightning combined, causing more than 7,800 official heat-related deaths in the United States between 1999 and 2010 (Karl et al. 2009). The Chicago heat wave of 1995 killed over 700 people (Davis et al. 2003) and the European heat wave of 2003 caused over 70,000 deaths (Robine et al. 2008). Official deaths account for only a portion of heat-related mortality because heat-related deaths are multi-factorial and there is a lack of a clear case definition when deaths occur (Ostro et al. 2009). As the planet warms, cities are warming more than many non-urban areas, pushing humans to live in hotter conditions than they have in the past, and putting into question the habitability of many cities worldwide (Estrada et al. 2017; Xu et al. 2020). North America is expected to see very large temperature increases compared to the global average (IPCC 2021).

The burden of extreme heat disproportionately affects low-income communities and people of color (Jesdale et al. 2013). These communities are more vulnerable due to higher risk of exposure to climate change hazards, structural and institutional conditions including limited access to services, higher economic inequality, and a lack of political representation that perpetuate poverty and limit adaptive capacity (Broto 2017). Black Americans are 52% more likely than average to live in areas where a high risk for heat-related health problems exists; Latino communities are 21% more likely to live under such conditions (Jesdale et al. 2013).

Extreme heat impacts a large number of people in Los Angeles (LA) because many residents lack the resources necessary to cope, such as adequate insulation or air conditioning (Li et al. 2020; Chakraborty et al. 2019). There is an 8% increase in all-cause mortality — deaths from all causes combined — during the hottest days in an average LA summer, even before factoring in a warming climate (Kalkstein et al. 2014). Consecutive days of heat can occasionally increase all-cause deaths by 30% (Kalkstein et al. 2014), and back-to-back extreme heat days are expected to occur more frequently in the future (Sheridan et al. 2012). Due to climatic and topographic variability in LA County, some cities will have 5 to 6 times the number of extreme heat days compared to current conditions (Hall et al. 2018). Continued warming is projected to increase average temperatures 2.2-2.8°C by mid-century, and by 2.8-4.5°C by the end of the century (Hall et al. 2018).

Urban forest cover and cool surfaces can combat heat

Tree planting is a heat mitigation strategy that has received investment in many cities around the world (Keith et al. 2020). Shading and evapotranspiration effects from trees offer the most significant ecosystem benefits for mitigating urban heat, contributing to decreases in park air temperatures by up to 6°C in comparison to surrounding streets (Vanos et al. 2012). In LA, higher urban forest cover (UFC) is correlated with lower ambient temperature: city blocks with more than 30% UFC are about 2.8°C cooler than blocks without (Pincetl et al. 2013). In addition to trees, structural improvements can be made to increase the albedo (or solar reflectance) of roofs, walls, and pavements to reduce air temperatures. Average ambient temperatures are reduced by 0.3°C per 0.10 increase in albedo across a city, and peak ambient temperatures decrease by up to 0.9°C (Santamouris 2014).

Scope and main objectives

This project models current and projected heat in LA and quantifies the effect that various UFC and albedo intervention scenarios could have on reducing temperatures and decreasing heat-induced deaths. The Los Angeles Urban Cooling Collaborative (LAUCC), a multi-disciplinary partnership of researchers and expert practitioners working with communities and government to understand and mitigate heat in LA, undertook this study to:

1. Identify the most heat-vulnerable geographic areas in Los Angeles County, California, USA.
2. Quantify how varying scenarios of increased UFC and albedo of roofs and pavements could impact summer temperatures; the number of oppressive air mass days which lead to elevated mortality; and heat-related mortality.
3. Estimate the number of years that climate change-caused warming could be delayed as a result of implementing the various UFC/albedo scenarios.

Methodology/approach

Synoptic climatology

Using historical weather and mortality data, we developed a model for LA County to test the impacts of four different UFC/albedo scenarios for the entire county and then in 11 smaller districts. We use "synoptic" climatology, which classifies days into discrete air mass types that traverse an area and have unique weather characteristics. Human health responds to an entire suite of weather variables that impact the individual simultaneously, and synoptic climatology provides a holistic evaluation that enables the identification of harmful conditions that lead to negative health impacts, including heat-related mortality (Hondula et al. 2014).

By considering observations of temperature, dewpoint, pressure, wind, and cloud cover four times daily for a particular location, we develop a "spatial synoptic classification" that categorizes days into air mass types (Sheridan 2002). Of about a dozen air masses that impact LA in summer, we focus on the two air masses associated with higher mortality rates: dry tropical (DT) and moist tropical plus (MT+) (Lee and Sheridan 2018).

County-level analysis

We first focus on how heat impacts human mortality in LA — that is, to what degree the number of average daily deaths that occur from all internal causes (deaths not caused by accidents or violence) increase under different heat wave conditions. We use patient-level mortality data provided by the California Department of Public Health to generate daily frequencies of the number of deaths resulting from all internal causes between May and October for the years 2000 through 2010. We use the Weather Research and Forecasting (WRF) model, version 3.8.1 (Chen et al. 2018), routinely used to simulate urban climates and the various processes occurring within an urban area, to model meteorological conditions and changes.

Correlating the mortality data with the meteorological data for the offensive DT and MT+ air masses, we arrive at the following statistically significant algorithm:

% MORT = -1.426 + 0.363 NFPTS + 5.219 DT + 1.609 MT + 0.057 AT05

Where:

- **% MORT** is the percent change in mortality from the baseline (average) value
- **NFPTS** is the Nairn-Fawcett Extreme Heat Factor, which evaluates heat in three consecutive day increments and determines whether the period before a heat wave has been hot or comfortable, which can have a significant impact on health outcomes (Nairn and Fawcett 2015)
- **DT** is a dummy variable which is added for the DT air mass days
- **MT** is a dummy variable for MT+ which is added for the MT+ days
- **AT05** is apparent temperature at 5:00 AM

Using this algorithm, we determine that during an average five-day heat wave in LA there are 4.1% more deaths above the baseline on the first day of the event, and 11.9% more deaths on the fifth day of the event. Clearly, heat is a significant threat to the health of residents of this region. We then estimate how various UFC/albedo scenarios would impact local meteorology relative to baseline conditions (Table 1).

We then model four historic heat waves, each with distinct humidity levels and heat intensity, occurring at different times during the summer season.

- Jul. 22-26, 2006: hot and humid, dominated by MT+ air mass days
- Jun. 19-22, 2008: drier event with both MT and DT days
- Aug. 26-30, 2009: less extreme, to evaluate a more common situation
- Sept. 26-29, 2010: very hot and dry event, dominated by DT days

Table 1: Tree cover and albedo scenarios tested. Low tree cover scenario is a 25% relative increase above baseline of 16.6%; Medium is a 100% increase; High is 40% total tree cover regardless of baseline. Low roof and pavement albedo means reflectance of .27 and .2, respectively; Medium is .37 and .25; High is .45 and .35.

	Tree Cover	**Albedo**
Case 1	Low	High
Case 2	High	Low
Case 3	Medium	Medium
Case 4	High	High

District-level analysis

We then segment LA County into smaller geographic areas to evaluate regional variations in heat-health sensitivity and effectiveness of interventions. Districts were designed to be as homogeneous as possible in socio-economic status, density, and climate. We selected a total of 11 districts, each with a population of about 300,000, and most of which are low-income and heat-vulnerable. We made the conservative assumption that UFC/albedo interventions would be applied only to the district being evaluated and not to any other part of the county. As with the county analysis, we developed a relationship between heat and mortality for each district and used the Nairn-Fawcett excess heat factor.

Climate change projections

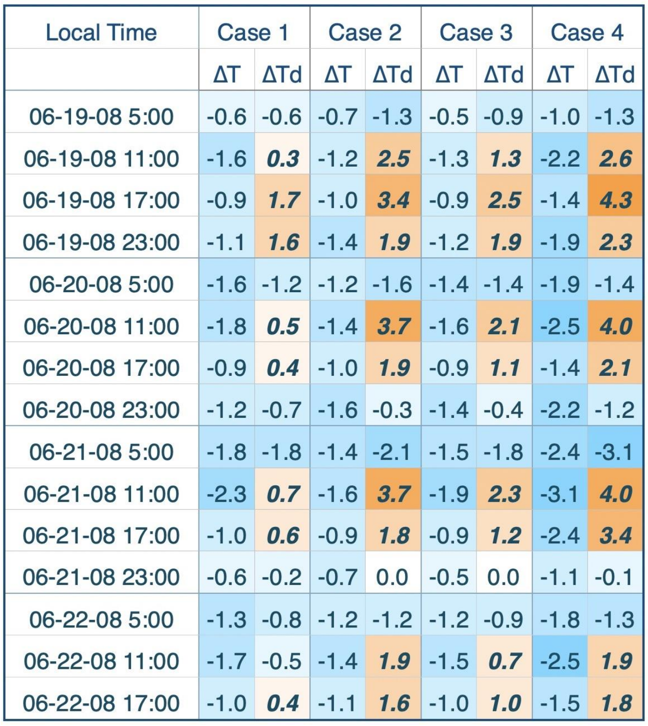
Using the Intergovernmental Panel on Climate Change-approved Representative Concentration Pathways (RCP) models 8.5 (business-as-usual) and 4.5 (moderate mitigation), we model the UFC/albedo scenarios and evaluate the impact on average temperatures in terms of how many years of climate change-caused warming could potentially be delayed. We first determine the mean reductions in maximum temperature for LA County using the UFC/albedo scenarios. The mean reduction for each scenario is just above 1°C for case 1, just below 1°C for cases 2 and 3, and 1.71°C for case 4. We looked at the 90th percentile of daily maximum temperature for the entire year and then just for summer (May through October). Using modeled data for the years 1950 to 2099, we determine the average temperature increases under RCP 8.5 and 4.5 (+0.034°C and +0.015°C per year, respectively). We then divide the average temperature reduction of each UFC/albedo scenario by those average annual temperature increases to determine how many years of warming could be delayed.

Results

County-level analysis

In this paper we present results for just one of the four heat waves. We discuss other heat events in de Guzman et al. 2020. We observe that UFC/albedo scenarios produce clear changes in temperature and dewpoint temperature under all scenarios. Temperatures show decreases in the range of 1-2°C; dewpoint temperatures show similar increases in magnitude (Table 2). Scenarios with more modest UFC increases show smaller changes than those with larger UFC increases, which is intuitive since UFC adds water vapor into the atmosphere, increasing dewpoint temperature. Nevertheless, the largest decreases in temperature also occur in cases 2 and 4, sometimes exceeding 3°C.

Table 2: Changes in meteorology for June 2008 heat wave. Delta T is the change in temperature (°C) from the baseline. Delta Td is the change in dewpoint temperature (°C) from the baseline. Increasingly dark blue represents greater reductions; increasingly dark orange represents greater increases.



Local Time	Case 1		Case 2		Case 3		Case 4	
	ΔT	ΔTd	ΔT	ΔTd	ΔT	ΔTd	ΔT	ΔTd
06-19-08 5:00	-0.6	-0.6	-0.7	-1.3	-0.5	-0.9	-1.0	-1.3
06-19-08 11:00	-1.6	***0.3***	-1.2	***2.5***	-1.3	***1.3***	-2.2	***2.6***
06-19-08 17:00	-0.9	***1.7***	-1.0	***3.4***	-0.9	***2.5***	-1.4	***4.3***
06-19-08 23:00	-1.1	***1.6***	-1.4	***1.9***	-1.2	***1.9***	-1.9	***2.3***
06-20-08 5:00	-1.6	-1.2	-1.2	-1.6	-1.4	-1.4	-1.9	-1.4
06-20-08 11:00	-1.8	***0.5***	-1.4	***3.7***	-1.6	***2.1***	-2.5	***4.0***
06-20-08 17:00	-0.9	***0.4***	-1.0	***1.9***	-0.9	***1.1***	-1.4	***2.1***
06-20-08 23:00	-1.2	-0.7	-1.6	-0.3	-1.4	-0.4	-2.2	-1.2
06-21-08 5:00	-1.8	-1.8	-1.4	-2.1	-1.5	-1.8	-2.4	-3.1
06-21-08 11:00	-2.3	***0.7***	-1.6	***3.7***	-1.9	***2.3***	-3.1	***4.0***
06-21-08 17:00	-1.0	***0.6***	-0.9	***1.8***	-0.9	***1.2***	-2.4	***3.4***
06-21-08 23:00	-0.6	-0.2	-0.7	0.0	-0.5	0.0	-1.1	-0.1
06-22-08 5:00	-1.3	-0.8	-1.2	-1.2	-1.2	-0.9	-1.8	-1.3
06-22-08 11:00	-1.7	-0.5	-1.4	***1.9***	-1.5	***0.7***	-2.5	***1.9***
06-22-08 17:00	-1.0	***0.4***	-1.1	***1.6***	-1.0	***1.0***	-1.5	***1.8***

Increases in dewpoint temperature can be partly attributed to cooling temperatures, especially for cases 2 and 4. As temperatures cool, vertical motion of the atmosphere and dispersal of near-surface moisture is inhibited. Thus, moisture from sources such as car exhaust, air conditioning, or trees is more likely to accumulate near the ground. However, decreases in air temperature are more consequential to human health than increases in dewpoint temperature. The apparent (or perceived) temperature is influenced more by a drop in temperature than a rise in dewpoint temperature.

Table 3: Changes in air mass type and mortality for each of the scenarios under during the June 2008 heat wave. 5AM apparent temperature (AT) and mean daily apparent temperature are displayed for each heat wave day. Red rows indicate percent increase/decrease in excess mortality over the mortality standardized value. The mean increase for all heat wave days is shown at the second row from the bottom. The net decrease in heat-related mortality from the baseline scenario is shown in the bottom row. Blue rows show air mass type.

		Baseline	Case 1	Case 2	Case 3	Case 4
6/19/08	SSC Type	MT	MT	MT	MT	MT
	5am AT	18.2	17.4	17	17.3	16.7
	Mean AT	23	22.2	22.5	22.4	22.1
	Mortality Increase %	1.2	1.2	1.1	1.2	1.1
6/20/08	SSC Type	MT	MT	MT	MT	MT
	5am AT	24.4	22.3	22.6	22.5	22
	Mean AT	25.1	23.6	24.3	23.9	23.4
	Mortality Increase %	1.9	1.7	1.7	1.7	1.6
6/21/08	SSC Type	DT	DT	DT	DT	DT
	5am AT	24.9	22.5	22.4	22.4	21.1
	Mean AT	26.4	24.9	25.5	25.3	24.6
	Mortality Increase %	11.0	8.5	9.5	9.1	8.1
6/22/08	SSC Type	TR	TR	TR	TR	TR
	5am AT	26.3	24.7	25.1	25.2	24.5
	Mean AT	24.9	23.8	24.3	24.1	23.8
	Mortality Increase %	13.5	12.1	13.2	12.7	11.7
Mean 4-day (6/19-22) increase in Mortality %		**6.9**	**5.9**	**6.4**	**6.2**	**5.6**
Net decrease in heat-related mortality cases		**n/a**	**-15%**	**-8%**	**-11%**	**-18%**

Changes in meteorology show a quantifiable impact on human mortality. A favorable outcome would be a reduction in the percent increase in mortality across the scenarios when compared to the baseline. The June 2008 heat wave (Table 3) provides an example. We estimate that 43 people died in LA from heat-related causes during this heat event. On June 19 and 20, the baseline shows an MT air mass is present. A DT air mass is present on June 21, while a transition air mass (TR) is present on June 22. In the baseline case, representing reality, the mortality increase is 1.2% above mean daily mortality. On June 21, the hottest day of the heat wave, the mortality increase is 11%; on June 22, it is 13.5%.

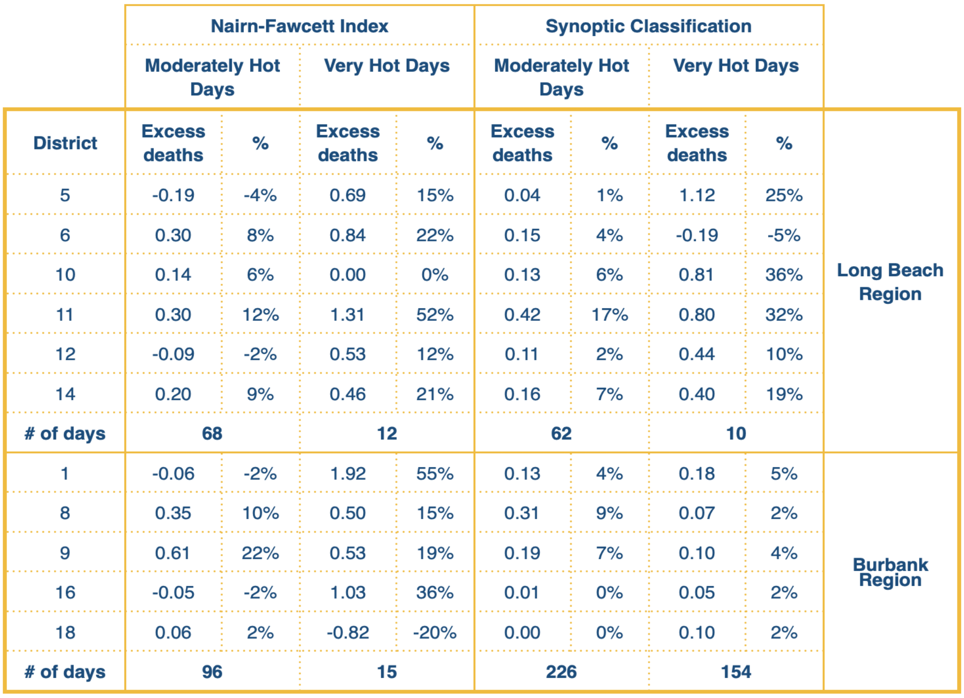
Looking at case 1 for June 19, we see no reduction in excess mortality although apparent temperatures are lower. Reductions are seen for the other days. For the entire heat event period, case 1 produces a 1% decline in excess mortality, from 6.9 to 5.9% — a relative 15% decrease in heat-related mortality representing about 6 saved lives (from 43 to 37 excess deaths). In contrast, case 2 only reduces mortality by 8% (or 3 deaths). Case 4, the most aggressive UFC/albedo scenario, reduces mortality by 18%, or about 8 deaths. We find these results encouraging, as they indicate that heat-related deaths can be reduced by up to 18% in a heat wave of this type. All four heat events evaluated in this county-level analysis demonstrate double-digit percentage decreases in mortality when UFC/albedo are increased, with other heat events showing even more encouraging results than those seen for June 2008. For example, during the September 2010 event, case 1 reduced mortality by 15%; case 2 by 22%; case 3 by 24%; and case 4 by 29%. A 29% reduction saved 23 lives based on our algorithm, from 78 deaths to 55. Several heat wave days also saw actual air mass changes to more benign air masses as a result of UFC/albedo intervention. These results will be shared in detail in a forthcoming peer-reviewed publication.

District-level analysis

Heat impacts the health of communities in LA County differently. Variations in heat vulnerability among districts appear related to socio-economic factors, with our analysis indicating that the burden is larger in lower-income, more densely-populated areas. Variations may also be influenced by the frequency and intensity of common heat waves, with hotter areas generally being less sensitive. Hotter neighborhoods are generally better adapted to heat both from a physiological and infrastructural standpoint. Heat variability appears to be a more significant risk factor than merely extremes in temperature.

Table 4. Results showing excess deaths during very hot days for 11 districts, in two LA climate regions of Long Beach (coastal) and Burbank (inland). Values on the left are based upon the Nairn-Fawcett index; values on the right are based

upon the spatial synoptic classification. Excess deaths represent average total deaths above/below the baseline for each category evaluated; % represents the percentage increase/decrease of anomalous deaths over the baseline total.

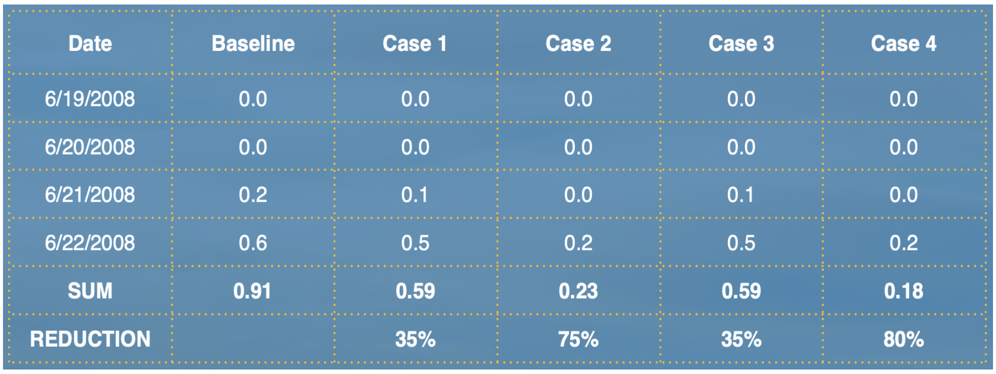


	Nairn-Fawcett Index				Synoptic Classification				
	Moderately Hot Days		Very Hot Days		Moderately Hot Days		Very Hot Days		
District	Excess deaths	%	Excess deaths	%	Excess deaths	%	Excess deaths	%	
5	-0.19	-4%	0.69	15%	0.04	1%	1.12	25%	Long Beach Region
6	0.30	8%	0.84	22%	0.15	4%	-0.19	-5%	
10	0.14	6%	0.00	0%	0.13	6%	0.81	36%	
11	0.30	12%	1.31	52%	0.42	17%	0.80	32%	
12	-0.09	-2%	0.53	12%	0.11	2%	0.44	10%	
14	0.20	9%	0.46	21%	0.16	7%	0.40	19%	
# of days	68		12		62		10		
1	-0.06	-2%	1.92	55%	0.13	4%	0.18	5%	Burbank Region
8	0.35	10%	0.50	15%	0.31	9%	0.07	2%	
9	0.61	22%	0.53	19%	0.19	7%	0.10	4%	
16	-0.05	-2%	1.03	36%	0.01	0%	0.05	2%	
18	0.06	2%	-0.82	-20%	0.00	0%	0.10	2%	
# of days	96		15		226		154		

However, outcomes vary. Some heat-vulnerable districts only demonstrate large mortality increases during days with the most extreme heat (Table 4). For example, during less severe heat, District 5 shows little or no excess mortality, but during more extreme heat mortality increases by 15%. The percentage rises to 25% when there are 4+ consecutive days. Conversely, District 11 shows high levels of excess mortality across all heat wave categories.

We see reductions in temperature in virtually all districts and under all UFC/albedo scenarios. Reductions are modest to moderate depending upon the district and time of day. The largest reductions generally occur midday. Mortality reductions often exceed 20% for more aggressive scenarios. For example, for District 6, reductions greater than 35% occur under all scenarios for June 2008, a common result in other districts as well (Table 5).

Table 5: Changes in excess mortality during June 2008 heat event in District 6. “Sum” row indicates total mortality for this four-day event; “Reduction” row indicates percent mortality reduction from baseline for each case.



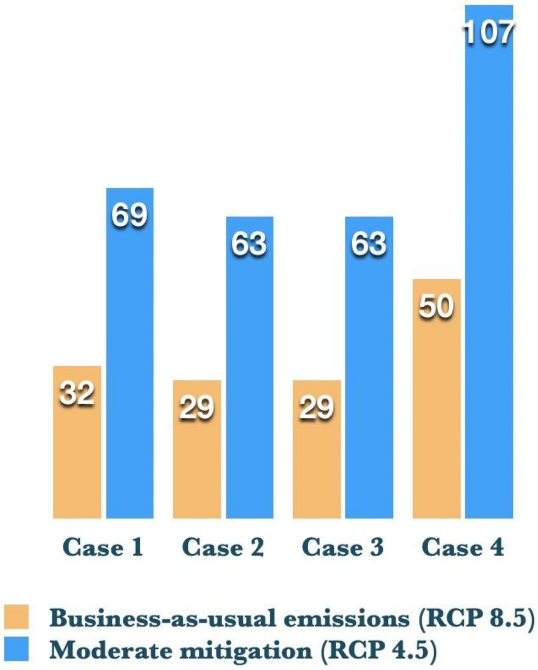
Date	Baseline	Case 1	Case 2	Case 3	Case 4
6/19/2008	0.0	0.0	0.0	0.0	0.0
6/20/2008	0.0	0.0	0.0	0.0	0.0
6/21/2008	0.2	0.1	0.0	0.1	0.0
6/22/2008	0.6	0.5	0.2	0.5	0.2
SUM	**0.91**	**0.59**	**0.23**	**0.59**	**0.18**
REDUCTION		**35%**	**75%**	**35%**	**80%**

Overall, hotter events produce greater excess mortality, and more aggressive land cover changes show greater reductions — with one to two of every four lives currently lost to heat potentially spared. For example, high-density, high-minority districts 1, 6, and 11 demonstrate highest mortality and often also have the greatest reductions under the intervention scenarios. Low-density higher-income districts 12, 14, and 18 show a less robust response, with low percentage mortality decreases or low excess mortality. Thus, we obtain a quantitative comparison of how different districts with unique socio-economic characteristics behave during various types of heat waves.

However, not all results are intuitive. District 10, which is a high-density, low-income district, shows non-significant findings. District 10 is socio-economically similar to District 11 (the most vulnerable district with the most encouraging results), but it does not show similar responses. This points to the possibility of social or other factors making this a more heat-resilient district, and warrants further investigation which we seek to pursue in a future research phase.

Climate change projections

Fig. 1: Years of delay of climate change-induced warming under UFC/albedo scenarios (source: de Guzman et al. 2020).



Results of the climate change analysis demonstrate that UFC/albedo scenarios could delay or even negate anticipated warming in LA County. Implementing case 4, for instance, would reduce temperatures by an average 1.7°C. By dividing 1.7 by 0.034 (anticipated annual warming under RCP 8.5), we arrive at 50 years of possible delay (Figure 1). This means climate change-caused warming could potentially be delayed 50 years relative to a business-as-usual emissions scenario if UFC/albedo were increased aggressively. In this example, LA could experience a climate in the year 2070 that was like the climate in 2020.

Discussion

The results of the county- and district-level analyses show that upwards of 25% of lives currently lost to heat could be saved if aggressive action is taken to increase UFC and albedo in LA. The climate change projections indicate that heat impacts of a changing climate could be delayed by 2 to 6 decades or more, depending on the emissions scenario. Heat wave temperatures can be reduced by 2-3^{o}C during the hottest times of day and even overnight, leading to a reduction in the magnitude of heat waves and related risk to heat-vulnerable individuals.

The scenarios are based on presently available cooling strategies, indicating that we currently have the ability to cool neighborhoods and cities sufficiently to change local meteorological conditions and reduce heat-related mortality. The heat wave of June 2008 represents only one event, and impacts of the UFC/albedo interventions show substantial reductions in temperature and mortality across all modeled heat waves. At the county level, the interventions occasionally produce a change in air mass from the most oppressive DT or MT+ categories to more benign categories that have a less harmful effect on human health.

Conclusions/ wider implications of findings

This study quantifies the critical service that urban forests and cool surfaces provide in cooling cities and protecting vulnerable urban dwellers from extreme heat. This indicates land cover modifications in LA County can save many lives during common heat waves. The research was completed by the Los Angeles Urban Cooling Collaborative (LAUCC), an interdisciplinary partnership of researchers and expert practitioners working with communities, nonprofit organizations, academia, private enterprise, and government toward the goal of understanding and implementing urban cooling strategies. This cooperative approach brought together physical and social scientists to make collaborative decisions about how to mitigate extreme heat in urban settings in ways that are scientifically, technologically, and socially feasible. The results have already been used to support local- and state-level policy and funding to move toward implementation of city cooling, including informing targets in the City and County of Los Angeles resilience and sustainability plans. These strategies can be adapted to combat extreme heat in other regions that are experiencing similar challenges.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

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References

Broto V. 2017. Urban Governance and the Politics of Climate change. World Dev. xx. https://doi.org/10.1016/j.worlddev.2016.12.031

Chakraborty T, Hsu A, Manya D, Sheriff G. 2019. Disproportionately higher exposure to urban heat in lower-income neighborhoods: a multi-city perspective. Environmental Research Letters, vol: 14 (10). https://doi.org/10.1088/1748-9326/ab3b99

Chen F, Kusaka H, Bornstein R, Ching J, Grimmond CSB, Grossman-Clarke S, Loridan T, Manning KW Martilli A, Miao S, Sailor D, Salamanca FP, Taha H, Tewari M, Wang X, Wyszogrodzki AA, Zhang C. 2011. The integrated WRF/urban modeling system: development, evaluation, and applications to urban environmental problems. Climatology (31) 273-288. https:// doi.org/10.1002/joc.2158

Davis RE, Knappenberger PC, Michaels PJ, Novicoff WM. 2003. Changing heat- related mortality in the United States. Environmental Health Perspectives, 111(14): 1712–1718.

de Guzman E, Kalkstein LS, Sailor D, Eisenman D, Sheridan S, Kirner K, Maas R, Shickman K, Fink D, Parfrey J, Chen Y, 2020. Rx for Hot Cities: Climate resilience Through Urban Greening and Cooling in Los Angeles. TreePeople. Available at: https://www.treepeople.org/wp-content/uploads/2020/09/RX-for-hot-cities-report.pdf [accessed 30.05.21]

Estrada F, Botzen W, Tol R. 2017. A global economic assessment of city policies to reduce climate change impacts. Nature Climate Change 7, 403–406. https://doi.org/10.1038/nclimate3301

Hall A, Berg N, Reich K, 2018. Los Angeles Summary Report. California’s Fourth Climate Change Assessment. Publication number: SUM-CCCA4-2018-007. Available at: https://climateassessment.ca.gov/regions/ [accessed 28.05.21]

Hondula DM, Vanos JK, Gosling SN. 2014. The SSC: a decade of climate-health research and future directions. Biometeorology (58) 109-120. https://doi.org/10.1007/s00484-012-0619-6

IPCC. 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte VP et al. (eds)]. Cambridge University Press. Available at: https://www.ipcc.ch/report/ar6/wg1/

Jesdale BM, Morello-Frosch R, Cushing L. 2013. The racial/ethnic distribution of heat risk-related land cover in relation to residential segregation. Environmental Health Perspectives, 121(7), 811–817.

Kalkstein LS, Sheridan SC, Kalkstein AJ, Vanos JK, Eisenman DP. 2014. The Impact of Oppressive Weather On Mortality Across Demographic Groups in Los Angeles County and the Potential Impact of Climate Change. Prepared for Los Angeles County Department of Public Health.

Karl TR, Melillo JM, Peterson TC (Eds.). (2009). Global Climate Change Impacts in the United States. Cambridge University Press.

Keith L, Meerow S, Wagner T. 2020. Planning for extreme heat: a review. Journal of Extreme Events. 6. 2050003.

Lee CC, Sheridan SC. 2018. A new approach to modeling temperature-related mortality: nonlinear autoregressive models with exogenous input. Environmental Research (164) 53-64. https:// doi.org/10.1016/j.envres.2018.02.020

Li D, Yuan J, Kopp R. 2020. Escalating global exposure to compound heat-humidity extremes with warming. Environmental Research Letters. https://doi.org/10.1088/1748-9326/ab7d04

Nairn JR, Fawcett RJ. 2015. The excess heat factor: A metric for heatwave intensity and its use in classifying heatwave severity. Environmental Research and Public Health 12(1) 227-53. DOI: 10.3390/ijerph120100227

Ostro B, Roth LA, Green RS, Basu R. 2009. Estimating the mortality effect of the July 2006 California heat wave. Environmental Research 109(5), 614-619. https://doi.org/10.1016/j.envres.2009.03.010

Pincetl S, Gillespie T, Pataki D, Saatchi S, Saphores J. 2013. Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. GeoJournal, 475-493, 78(3).

Robine JM, Cheung SLK, Le Roy S, Van Oyen H, Griffiths C, Michel JP, Herrmann FR. 2008. Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies, 331(2): 171–178.

Santamouris M. 2014. Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Solar Energy. 103.

Sheridan SC, Lee CC, Allen MJ, Kalkstein LS. 2012. Future heat vulnerability in California, Part I: Projecting future weather types and heat events. Climatic Change, 115(2), 291-309. DOI:10.1007/s10584-012-0436-2

Sheridan SC. 2002. The redevelopment of a weather-type classification scheme for North America. Climatology, 22(1). https://doi.org/10.1002/joc.70**9**

Vanos JK, Warland JS, Gillespie TJ, Slater GA, Brown RD, Kenny NA. 2012. Human energy budget modeling in urban parks in Toronto and applications to emergency heat stress preparedness. Journal of Applied Meteorology & Climatology, 51(9), 1639-165. 10.1175/JAMC-D-11-0245.1

Xu C, Kohler TA, Lenton TM, Svenning J, Scheffer M. 2020. Future of the human climate niche. Proceedings of the National Academy of Sciences, 117 (21) 11350-11355. DOI: 10.1073/pnas.1910114117