Creating and Mapping an Urban Heat Island Index for California

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Executive Summary

Background

Urban climates can impact local meteorological fields, emissions of heat and pollutants, and photochemical production of ozone. One relatively well-documented characteristic of urban climates is the urban heat island (UHI). UHIs can locally exacerbate the effects of regional and global climates on heat and air quality especially during summer. This exacerbation can have particularly detrimental implications during heat events and heat waves with significant ramifications in terms of public health, from both heat and air-quality pathways. As a result of UHIs, cooling energy demand increases, emissions of pollutants increase, the photochemical production of ozone accelerates, and air quality deteriorates further. Because of these potential negative impacts, efforts at the city and regional levels are being undertaken to better characterize UHIs and propose effective mitigation measures. Pursuant to AB 296, the California Environmental Protection Agency (CalEPA) has initiated an effort to quantify the UHI and develop a UHI Index (UHII) for California.

Methods

In this CalEPA-supported study, the UHI was characterized via detailed meteorological modeling of California. A UHII was then defined and calculated for each census tract in a number of selected urban areas. The ultimate goal of developing the UHII is for use in assessing the potential heat health implications of urban land use and UHI, identifying geographical areas where UHIs can exacerbate environmental health issues, and possibly as an additional layer of information for use with the CalEnviroScreen tool. The UHII is an indicator to the exacerbation of heat by urban areas, as measured by the urban-nonurban temperature difference.

During the initial stages of the study, a definition of the UHII was developed. Several variations of the definition, with various degrees of complexity, were considered and evaluated. Based on directives from CalEPA and the Project Oversight Workgroup (POW), a simple definition of the UHII was adopted:

$$UHII = \sum_{h=1}^{H(JJA)} \left[T_{u,k,h} - min\left(T_{u,k,h}, T_{nu,k,h}\right)\right]$$

where $T_{u,h}$ is the urban temperature at time-step h, $T_{nu,h}$ is the nonurban temperature at time-step h, H is the number of time-steps, and k is the location index (census tract). The calculation yields a cumulative UHII (in degree-hours) over designated periods, in this case June, July, and August 2013 and 2006.

Following the establishment of the UHII definition, the modeling system was prepared for the application. Project tasks included 1) preparing and generating the needed surface and atmospheric input data, 2) characterizing the land use and land cover at fine resolutions throughout the state of California, 3) updating, modifying, and customizing the model parameterizations and urban representations, 4) testing the various components of the model, 5) performing detailed statistical evaluation of model performance against modeling-community-recommended performance benchmarks, 6) applying the models and calculating the UHII for every census tract in the selected urban areas, and 7) analyzing the results and characterizing and mapping the UHII.

Results

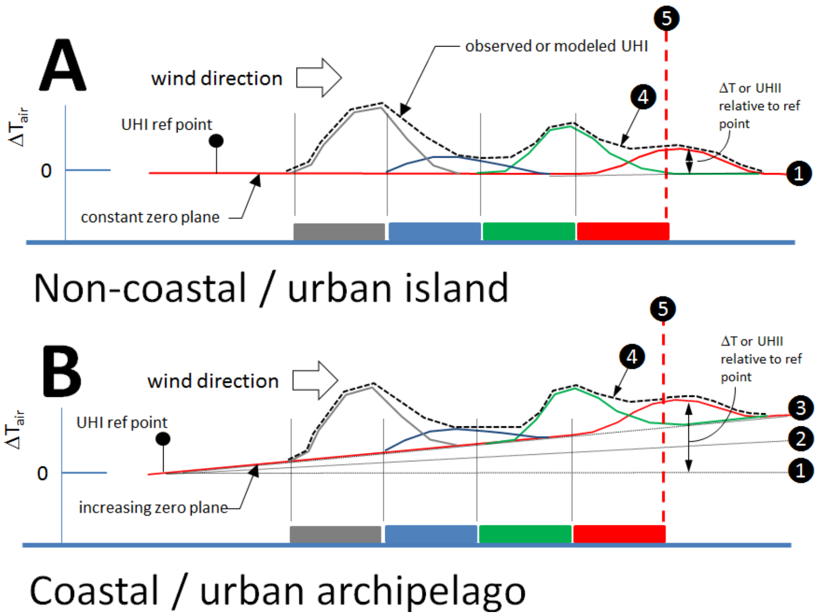
The UHII was calculated for each census tract in terms of total degree-hours (DH) over the modeled seasons, DH per day averages, as well as other metrics such as temperature differences and time series. The UHII spatial patterns were grouped into small, large, inland, urban archipelago[1], and coastal areas, as well as single or multiple-core UHIs (Figure ES-1, A,B). The UHII was characterized under typical summer conditions during the selected periods as well as during excessive heat events such as during the 2006 heat wave. Because of the large number of census tracts analyzed and because of the varying microclimates in California, there is correspondingly a large range of UHI and UHII values in different regions. At the lower end of the scale (in smaller urban areas), the UHII ranges from 2 to 20 DH/day (°C.hr/day) whereas at the higher end (larger urban areas), it reaches up to 125 DH/day or more. The largest average temperature difference (largest average UHI) in each region ranges from 0.5 – 1.0°C at the lower end and up to 5°C or more at the higher end.

Spatial patterns of the UHI were also analyzed. The modeling shows that urban areas with relatively well defined boundaries (i.e., urban islands) typically exhibit single- or multi-core UHIs, e.g., Figure ES-2 (left). On the other hand, large urban archipelagos and coastal regions, such as the Los Angeles Basin and the Santa Clara Valley (Figure ES-1, B) consist of sustained and contiguous urban land use with no well-defined boundaries, except for breaks by topography. In this case, the UHI often peaks in areas near the downwind edges of the archipelago. Thus whereas in urban islands the local UHI is mostly a result of local processes that are strongly dependent on local land-use properties (line 4 minus line 1 in Figure ES-1, A), the local UHI in an archipelago / coastal areas (line 4 minus line 1 in Figure ES-1, B)

[1] The term “archipelago” is used in this study to refer to large, continuous urban expanses with sustained density of development and urban land use.

additionally includes the superimposed effects of on-shore warming (line 2 minus line 1) and upwind urban warming (line 3 minus line 2).

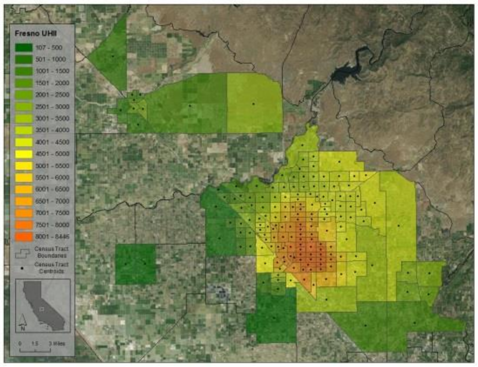
Figure ES-1. Conceptual depiction of localized UHIs, urban archipelago-induced and on-shore warming in urban islands (A) and urban archipelagos (B).

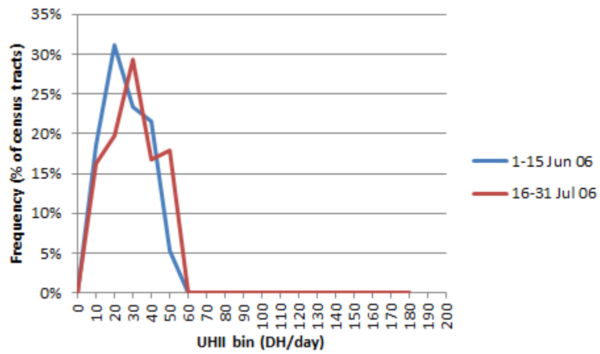


The modeling also captures the synergies between the UHI and regional climate. The analysis shows that compared to cooler periods, warmer weather, e.g., during a heat wave, enhances the UHI and shifts the UHII towards larger values. The example in Figure ES-2 for an arbitrary location (Fresno) shows a map of total UHII (DH per 182 days), as well as a frequency distribution of census tracts across a range of UHII bins. It can be seen that the heat wave event of July 16-31, 2006 shifts a number of census tracts towards higher UHII values (bins) relative to a cooler period of time in June 1 – 16, 2006. Several California urban area examined in this study also exhibit this pattern of larger UHII during the heat wave. The implications are that as heat waves become possibly more frequent because of changes in climate, they can intensify the UHIs in many regions, further exacerbating heat stress in urban areas. Thus mitigation measures, such as cool cities and sustainability, will become even more important in the future.

Coastal urban areas with deep basins and catchment zones, such as Los Angeles basin and the Santa Clara Valley, exhibit a slightly different pattern of UHII shift during warmer weather because of stronger local venting during such conditions. In these cases the temperature, while larger in absolute values than during the cooler periods, becomes more uniform across the basin and thus the UHII, by definition becomes more uniform.

Figure ES-2. Left: Spatial distribution of total UHII in the Fresno region. **Right:** Frequency distribution (percent of census tracts in the area) of UHII bins (blue: coolest period, red: heat wave).





Conclusions

In this study, the UHII was developed and calculated solely for characterizing and quantifying the effects of urban areas in exacerbating heat under existing conditions. As such, the computed UHII can be used to identify vulnerable geographical areas and/or possibly as an additional layer of information for potential use in conjunction with the CalEnviroScreen tool. As discussed in this report, there are several additional levels of UHII beyond what was completed in this study, which can be developed in the future. These include UHII indicators tailored for mitigation purposes and implementation of cool cities or other control measures. It is recommended that these additional levels of the UHII be developed and quantified as part of follow-on research to characterize both positive and negative effects of potential mitigation measures and prioritize their deployments. It is also recommended that the synergies between UHI and heat waves be further studied and quantified in order to assess the benefits of control measures, such as cool cities, in future years.