REMOTE SENSING OF THE URBAN HEAT ISLAND EFFECT ACROSS BIOMES IN THE CONTINENTAL USA

Ping Zhang[1, 2]*, Marc L. Imhoff*[1]*, Robert E. Wolfe*[1]*, and Lahouari Bounoua*[1]

1. Hydrospheric and Biospheric Science Laboratory, NASA's Goddard Space Flight Center
2. Earth Resource Technology Inc

1. INTRODUCTION

Urban heating and the formation of the urban heat island (UHI) is one attribute of urban land transformation that is of interest across science disciplines because the UHI signal reflects a broad suite of important land surface changes impacting human health, ecosystem function, local weather and possibly climate. In this paper we use a combination of satellite and ecological map data to characterize and inter-compare the UHI response across biomes in the continental US. We examine the relationship between % Impervious Surface Area and land surface temperature across many cities, calculate seasonal UHI for cities in similar ecological settings, and compare the amplitude of the UHI for the major biomes.

2. DATA AND METHODOLOGY

Impervious surface area (ISA) from the NLCD2001 and land surface temperature (LST), Normalized Difference Vegetation Index (NDVI), and visible band Aledo from MODIS averaged over three annual cycles (2003-2005) are used in a spatial analysis to assess the urban heat island (UHI) skin temperature amplitude and its relationship to development intensity, size, ecological setting, and surface reflectance for more than 300 urban area (with area larger than 10 km^2) over the continental USA.

Development intensity zones based on %ISA are defined for each urban area emanating outward from the urban core to the non-urban rural areas nearby and used to stratify sampling for land surface temperatures, NDVI, and visible band Albedo [Fig. 1.]. Sampling was further constrained by biome and elevation to insure objective inter-comparisons between zones and between settlements in different biomes. Stratification based in ISA permits the definition of hierarchically ordered zones that are consistent across urban areas in different ecological setting and across scales.

3. RESULTS

We find that ecological context and settlement sizes significantly influence the amplitude of summer daytime UHI (urban-rural temperature difference). An average of 7.1 ^{o}C UHI is found in cities built in biomes dominated by forests; 4.2 ^{o}C UHI in cities embedded by grass/shrubs; and only a weak heat island or sometime heat sink in cities in deserts. The average summer daytime UHI is 6.4 ^{o}C for cities larger than 500 km^2, compared to 5.1 ^{o}C for USA cities smaller than 50 km^2 and larger than 10 km^2. On a yearly average, urban areas are substantially warmer than the non-urban fringe by 3.8 ^{o}C at daytime. The average amplitude of the UHI is remarkably asymmetric with a 5.6 ^{o}C temperature difference in summer and only 2.0 ^{o}C in winter.

The amplitude of UHI is found to be significantly negative correlated (R=-0.70) with vegetation activity difference between urban and rural represented by MODIS NDVI. For each 10% decrease in the Urban-Rural NDVI difference, the UHI increases approximately 1.66 ^{o}C. This relationship is similar and extends the results described in Gallo et al. in which the AVHRR NDVI data were linearly related to differences in observed urban and rural minimum temperatures in 37 US cities [2]. Our results also shows significantly positive relationships (R=0.59) between UHI and surface reflectance difference between urban and rural represented by MODIS visible band Albedo.

We find that impervious surface area is one of the primary drivers for increase in temperature with variations in different ecological context [Fig. 2]. For all cities combined, ISA is the primary driver for increase in temperature explaining 72% of the total variance in LST. The ISA/LST relationship is strongest for urban areas in forested biomes where variations in ISA explain 88% of the variation in LST. The rate of change in LST as a function of ISA is 11.5% for urban areas in forests (indicating an LST increase of 1.15 ^{o}C for a 10% increase in ISA), while only 6.9% for those characterized by short vegetations. In desert environments, the LST's response to ISA presents an uncharacteristic "U-shaped" horizontal gradient decreasing from the urban core to the outskirts of the city and then increasing again in the suburban to the rural zones. If only Las Vegas and Phoenix are considered, more than 70% of the LST variance is explained by changes in ISA through a polynomial relationship.

Overall, our results indicate a possible way to examine and compare the amplitude as well as the driver of the UHI at continental scale. The implications are that for urban areas developed within forested ecosystems the summertime UHI can be quite high relative to the wintertime UHI suggesting that the residential energy consumption required for summer cooling is likely to increase with urban growth within those biomes.

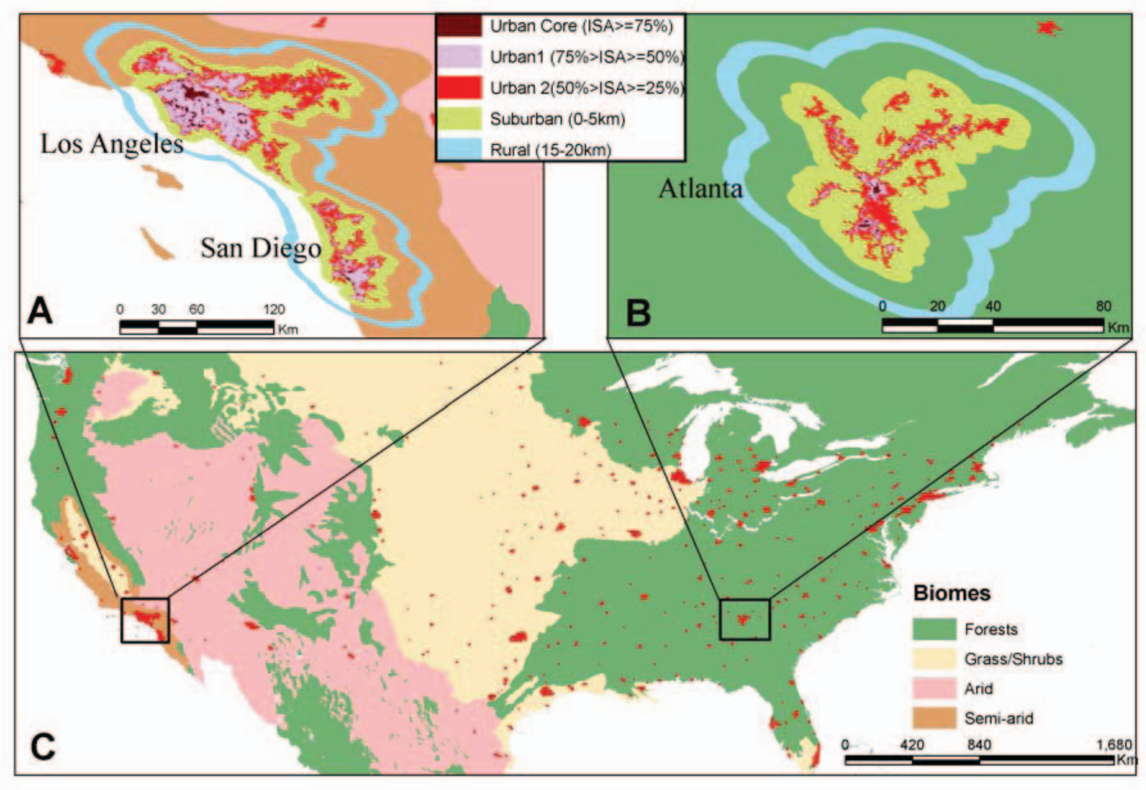

Figure 1: Panels A and B show examples of the typical layout of the 5 urban zones defined for each city. Urban Core, Urban1 and Urban2 are based on %ISA of each pixel. The Suburban zone is composed of pixels with less than 25% ISA occurring within a 5km wide ring adjacent to the 25% ISA contour. The Rural zone is a ring 15-20 km distance from the 25% ISA contour. Pixels that cross biomes or significant changes (± 50m) in elevation are excluded. Panel C shows 323 USA cities used in this analysis and their biomes according to Olson et al. [1]

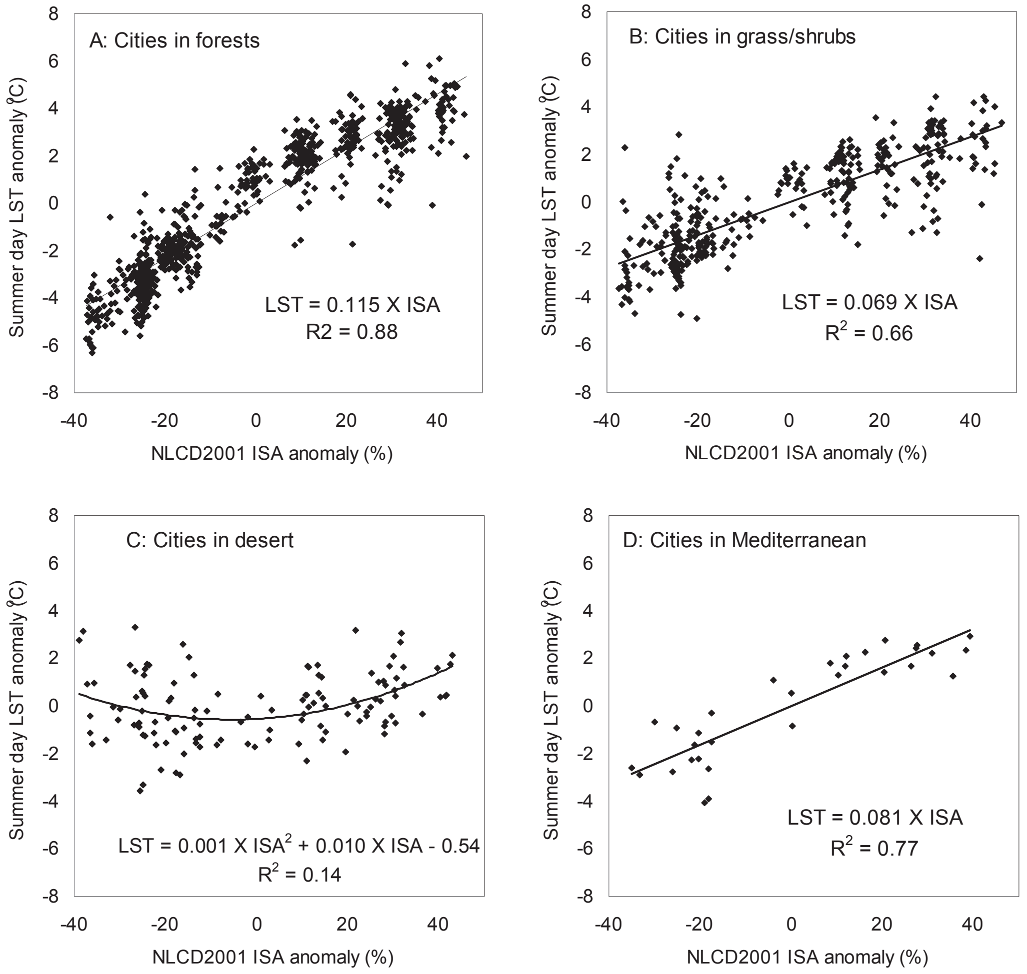

Figure 2: The relationship between summer daytime LST anomaly and ISA anomaly for USA cities in forest (Panel A), grass/shrubs (Panel B), desert (Panel C), and Mediterranean (Panel D).

REFERENCE

[1] Gallo, K. P., McNab, A. L., Karl, T. R., Brown, J. F ., Hood, J. J. and Tarpley, J. D. 1993. “The use of NOAA AVHRR data for assessment of the urban heat island effect”. *Journal of Applied Meteorology*, Vol. 32, No. 5, pp. 899-908.

[2] Olson, D M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D'Amico, I. Itoua, H.E. Strand, J.C. Morrison, C.J. Loucks, T.F. Allnutt, Thomas F, T.H. Ricketts, Y. Kura, J.F. Lamoreux, W.W. Wettengel, P. Hedao, K.R. Kassem, 2001. “Terrestrial Ecoregions of the World: A New Map of Life on Earth”. *BioScience*, Vol. 51, No. 11, pp. 933-938.