Remote Sensing of the Urban Heat Island Effect Across Biomes in the Continental USA

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Studying the UHI Phenomenon

- Focus on surface temperature

  - influenced by albedo, emissivity, and surface fluxes.

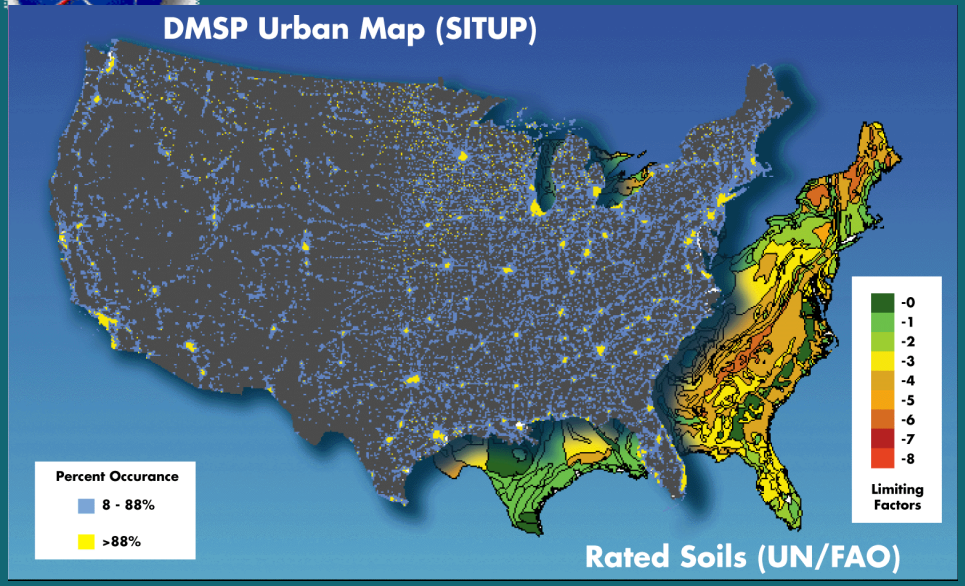
- Bioclimatic context

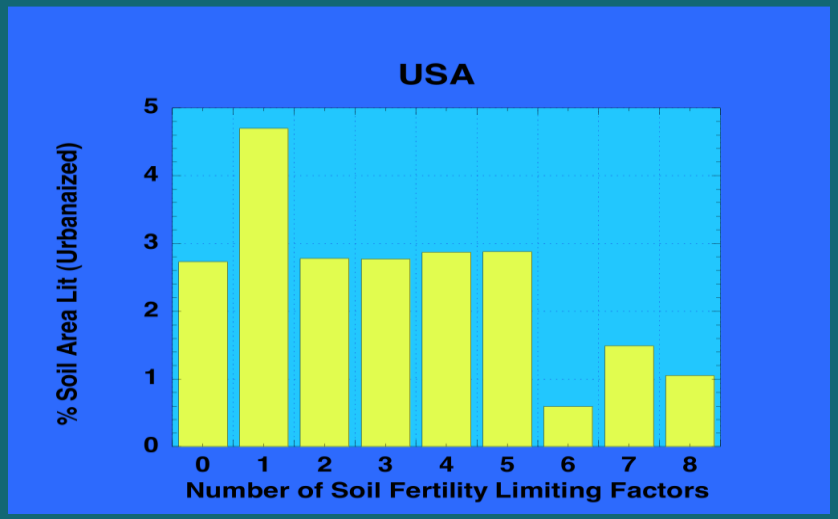
  - setting is important as UHI is a relative measure (Temp of urban core compared to nearby non-urban cover).

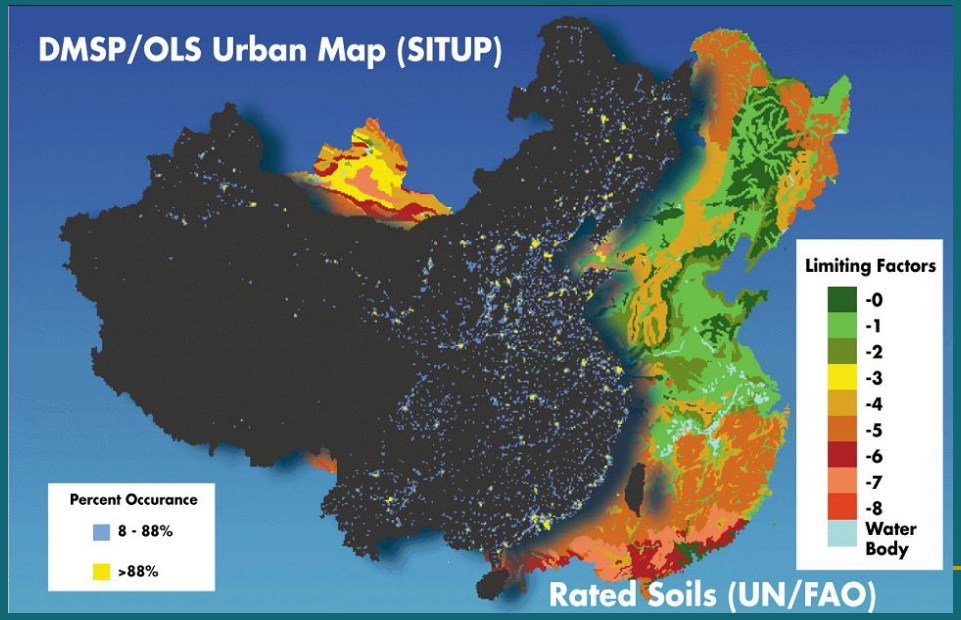
  - Important to climate change as urbanization of specific biomes represents a departure from previous flux characteristics.

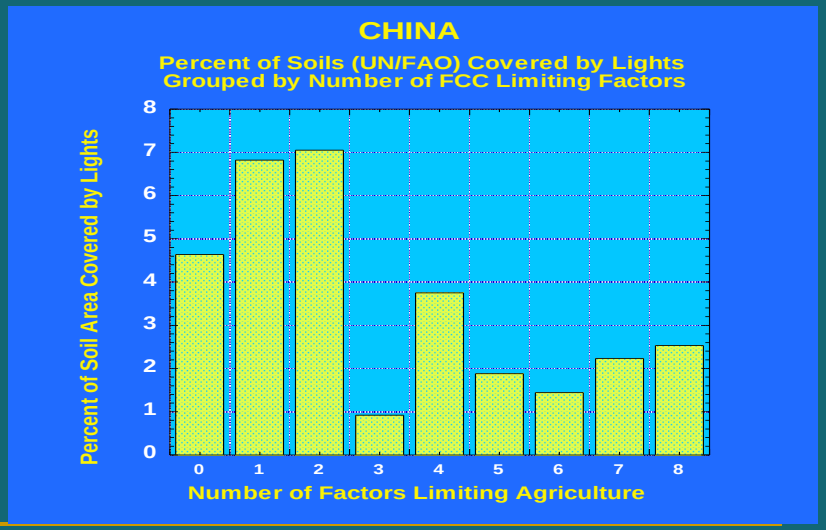
    - **Impact may be disproportionate to simple area based assessments**.

Urban Occupation of Fertile Soils



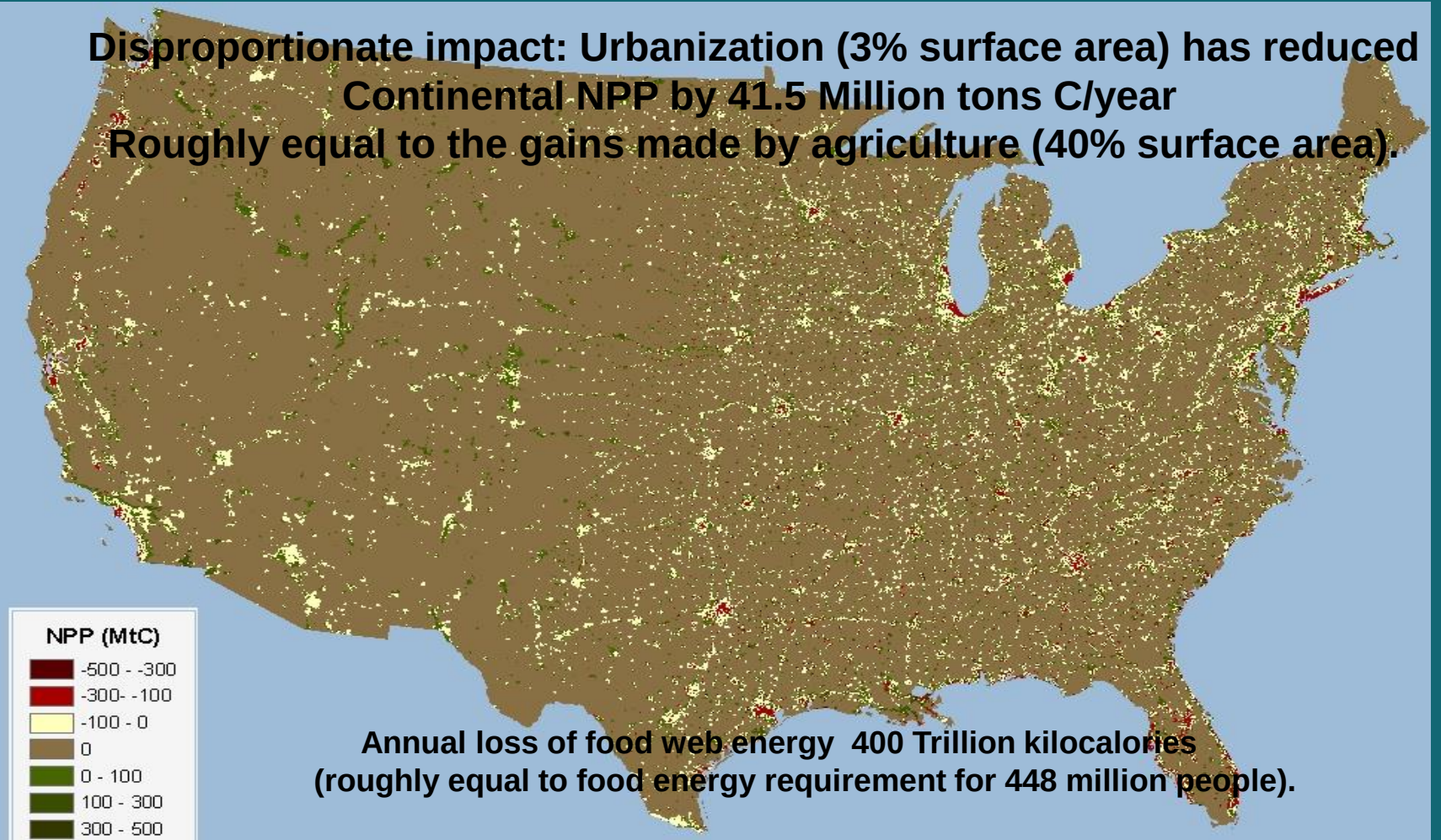






Consequences of Urbanization
NPP Lost or Gained (annually) going from a pre-urban to a post urban world

Disproportionate impact: Urbanization (3% surface area) has reduced Continental NPP by 41.5 Million tons C/year
Roughly equal to the gains made by agriculture (40% surface area).



Annual loss of food web energy 400 Trillion kilocalories
(roughly equal to food energy requirement for 448 million people).

Reduction of actual food products for 16.5 million persons annually.

Imhoff et al. 2004, RSE, Vol. 89, Issue 4, pp. 434-443.

Consequences of Urbanization on NPP

Satellite Observations

DMSP/OLS Urban Map

Urban, Peri-urban, Non-urban

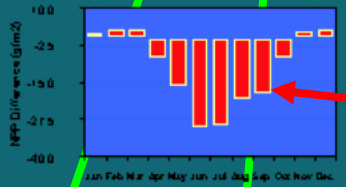
AVHRR

Monthly NPP (g Cm^{-2})

NPP and Local Climate:

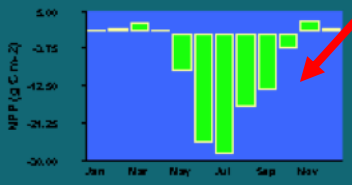
Urban Heating Extends Length of growing season locally in cold climates.

North East

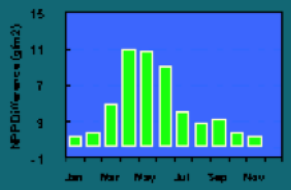


Winter NPP gain negated in peak season by reduced vegetation and heat stress.

Mid-Atlantic

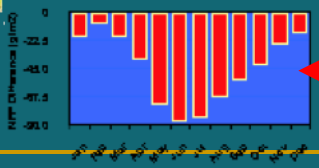


South West



In semi-arid regions cities enhance NPP relative to surrounding areas

South East



Seasonal Offset diminishes in tropics

Surface Temperature and Albedo

120°F

49°C

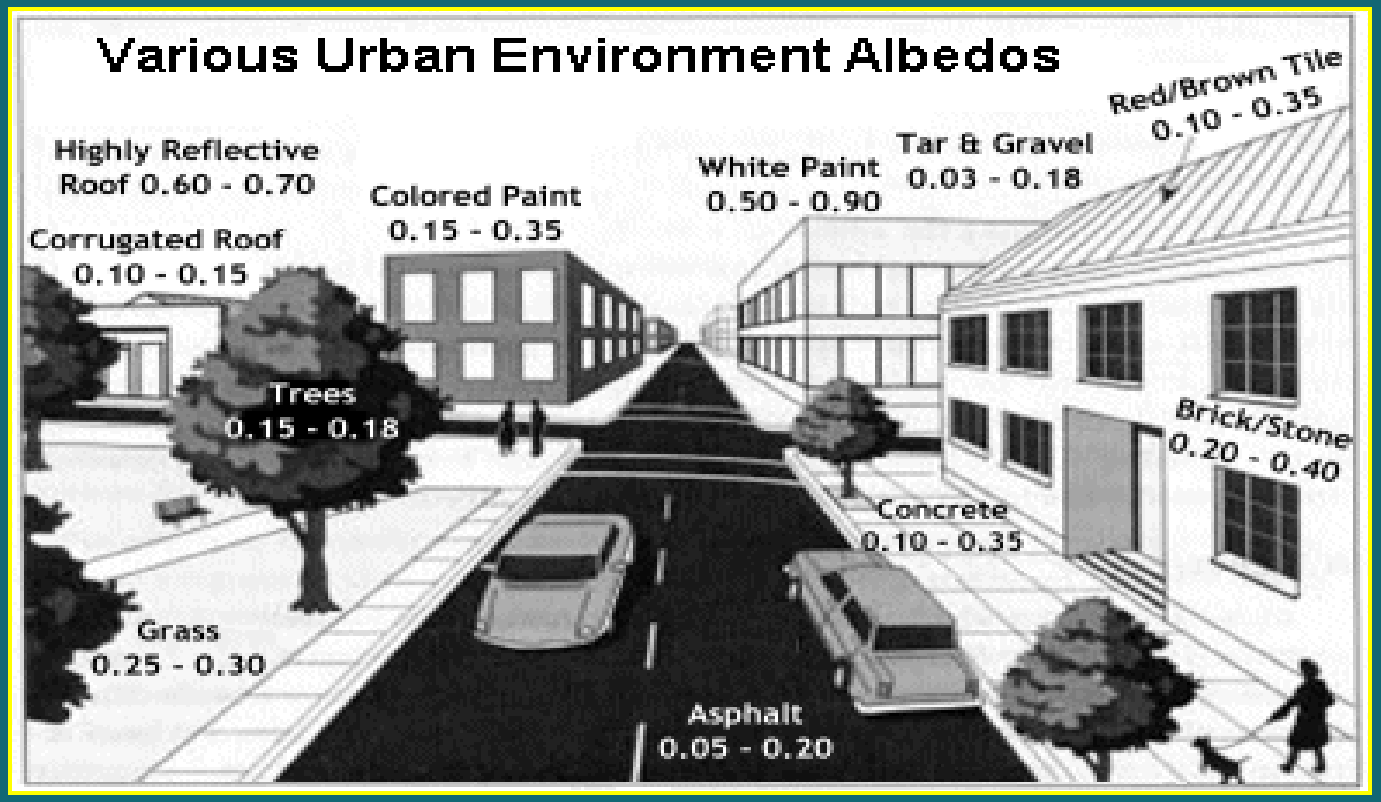
83°F

28°C

Atlanta Urban Heat Island and Air Quality Modeling Study

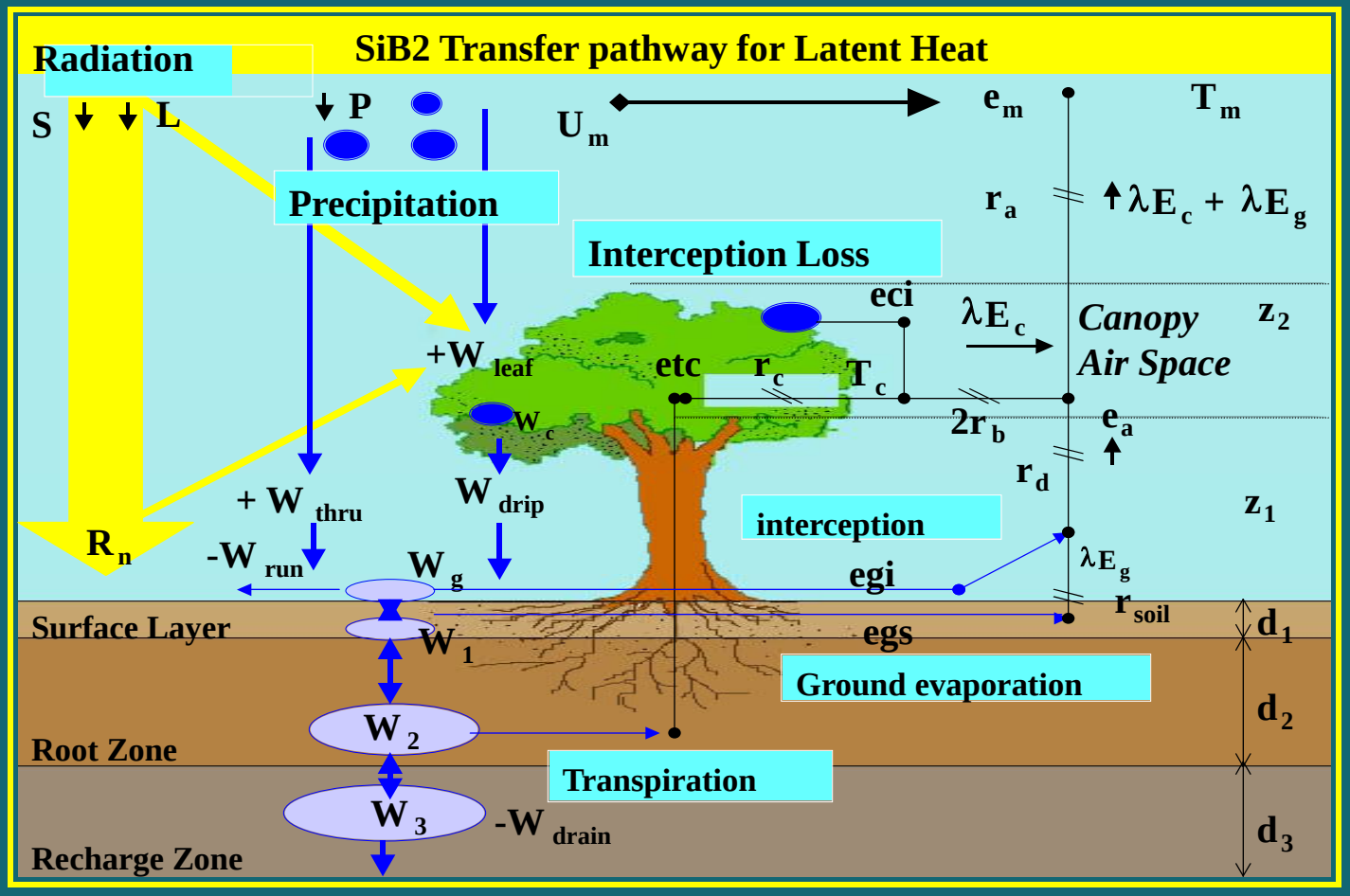
D. Quattrochi, MSFC

Surface composition (parameters) in and outside urban area



More than Albedo

Biome Level Surface Parameters Influence Heat



Schematic functioning of the Simple Biosphere Model (SiB2) showing the pathway for the latent heat flux calculation.

Datasets and compilations

- *Domains:* **cities in U.S.**
- *Scales:* **cities with area size from 10km^2 to more than 4000 km^2**
- *Datasets:*

- Impervious surface area (ISA) from the Landsat TM-based NLCD 2001 dataset [Yang et al., 2002]

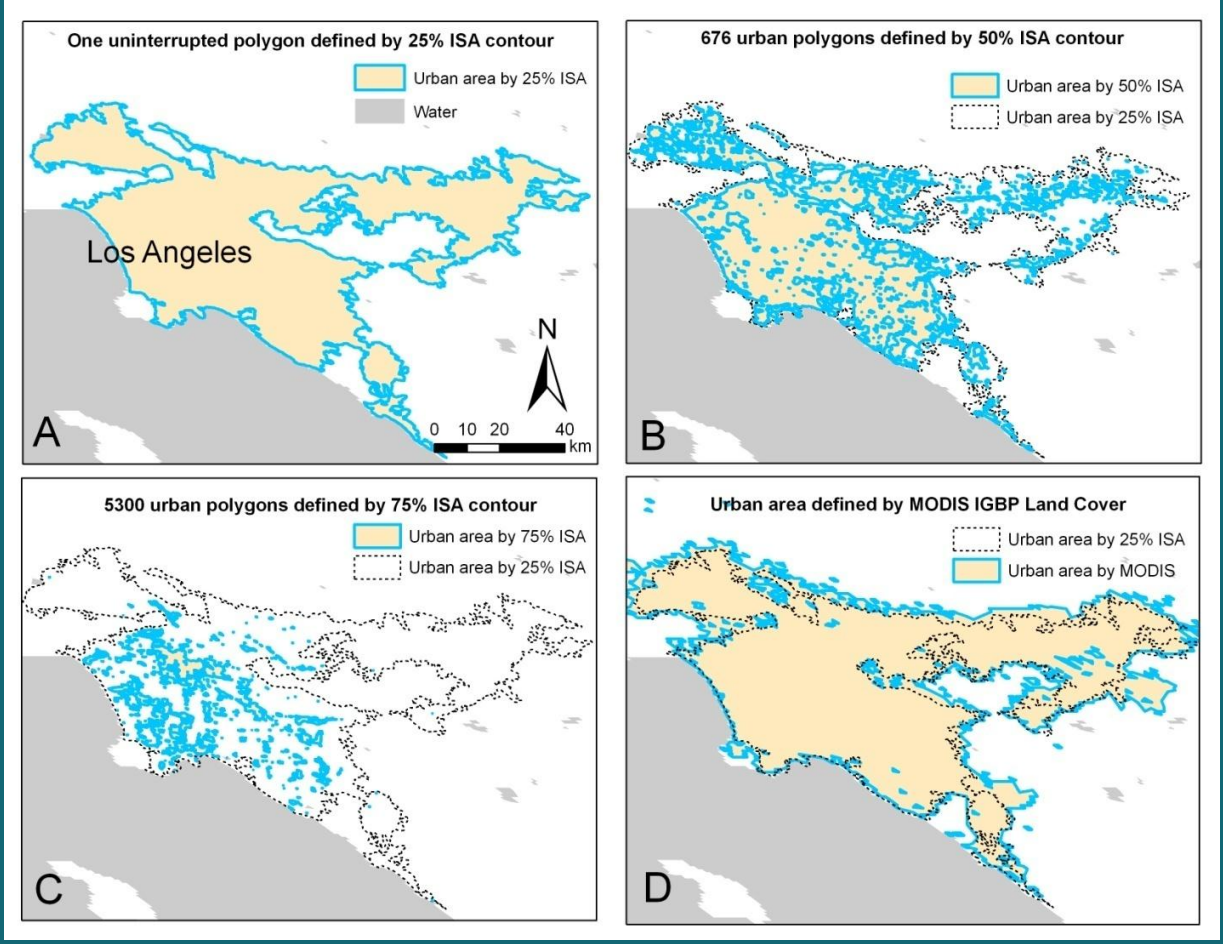
- Land surface temperature (LST) from MODIS [Wan et al., 2004]

- Terrestrial ecoregion map developed by Olson et al [2001]

- Topographic data from SRTM30 [Farr and Kobrick, 2000]

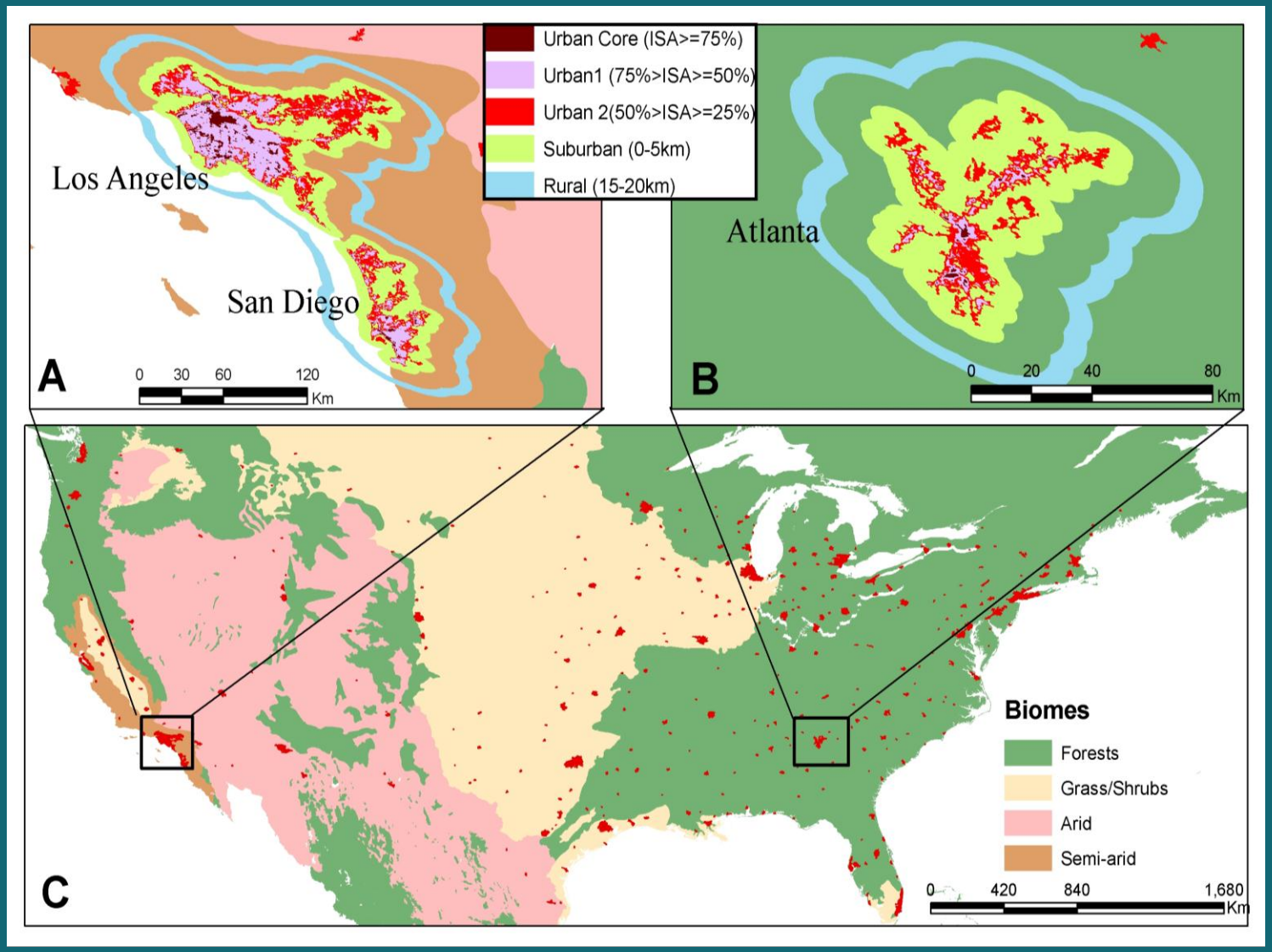
- NDVI from MODIS [Huete et al., 1997]

Geospatial urban area definition using Landsat Impervious Surface Area



- Identifies boundary between urban and low intensity residential area
- Provide spatially coherent urban groups

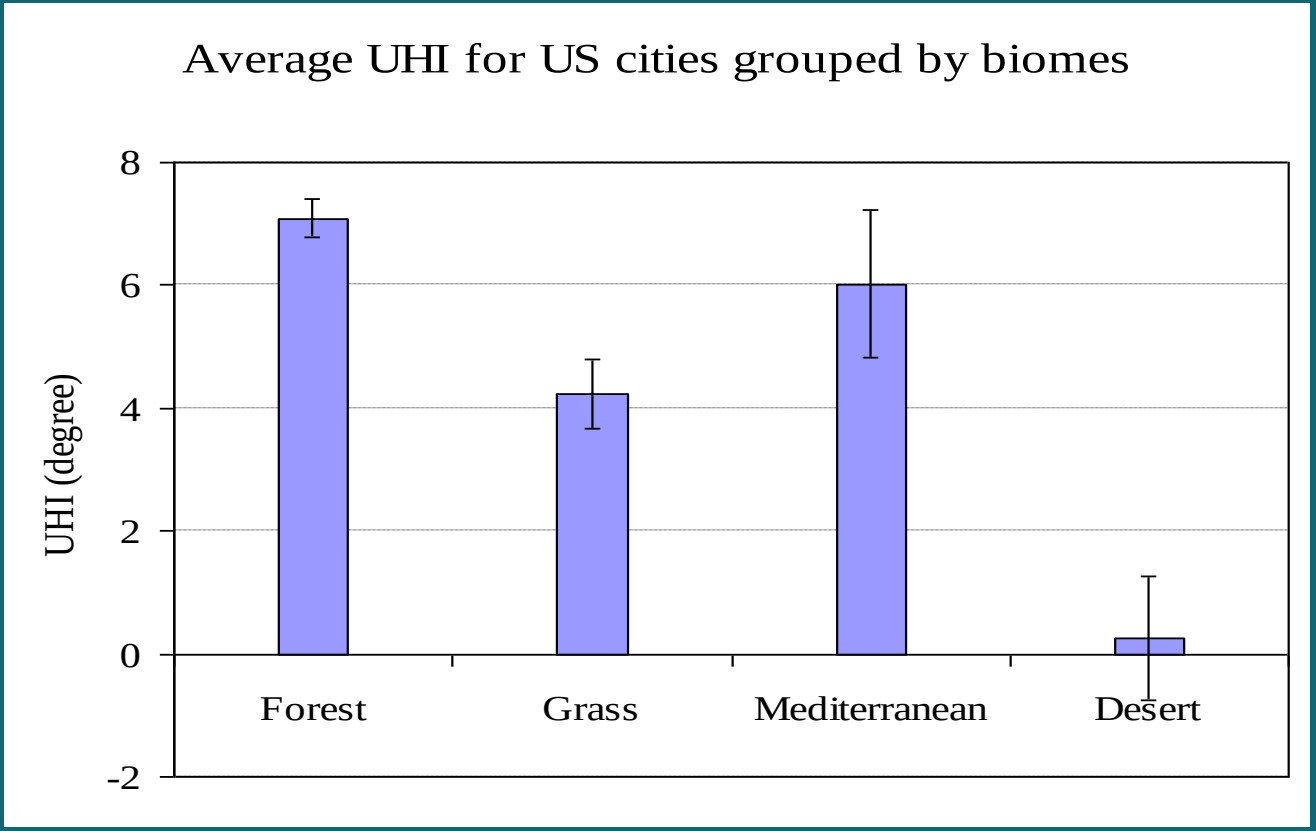
Classification of urban density



Classification of urban density

- Four broad biomes: forest, grass/shrub, arid (desert and xeric shrubland), and semi-arid (Mediterranean)
- 323 settlements are evenly distributed over USA ranging from around 10 km^2 to more than 4,000 km^2
- Five urban zones are defined based on ISA density
  - Urban core pixels: 75% > ISA ≥ 50%
  - Medium density urban pixels: 50% > ISA ≥ 25%
  - Suburban pixels: 0 to 5 km outside the 25% ISA contour
  - Rural pixels: 15 to 20 km outside the 25% ISA contour
- Sampling is constrained by biome and elevation
- $UHI = LST_{urban\ core} - LST_{Rural}$

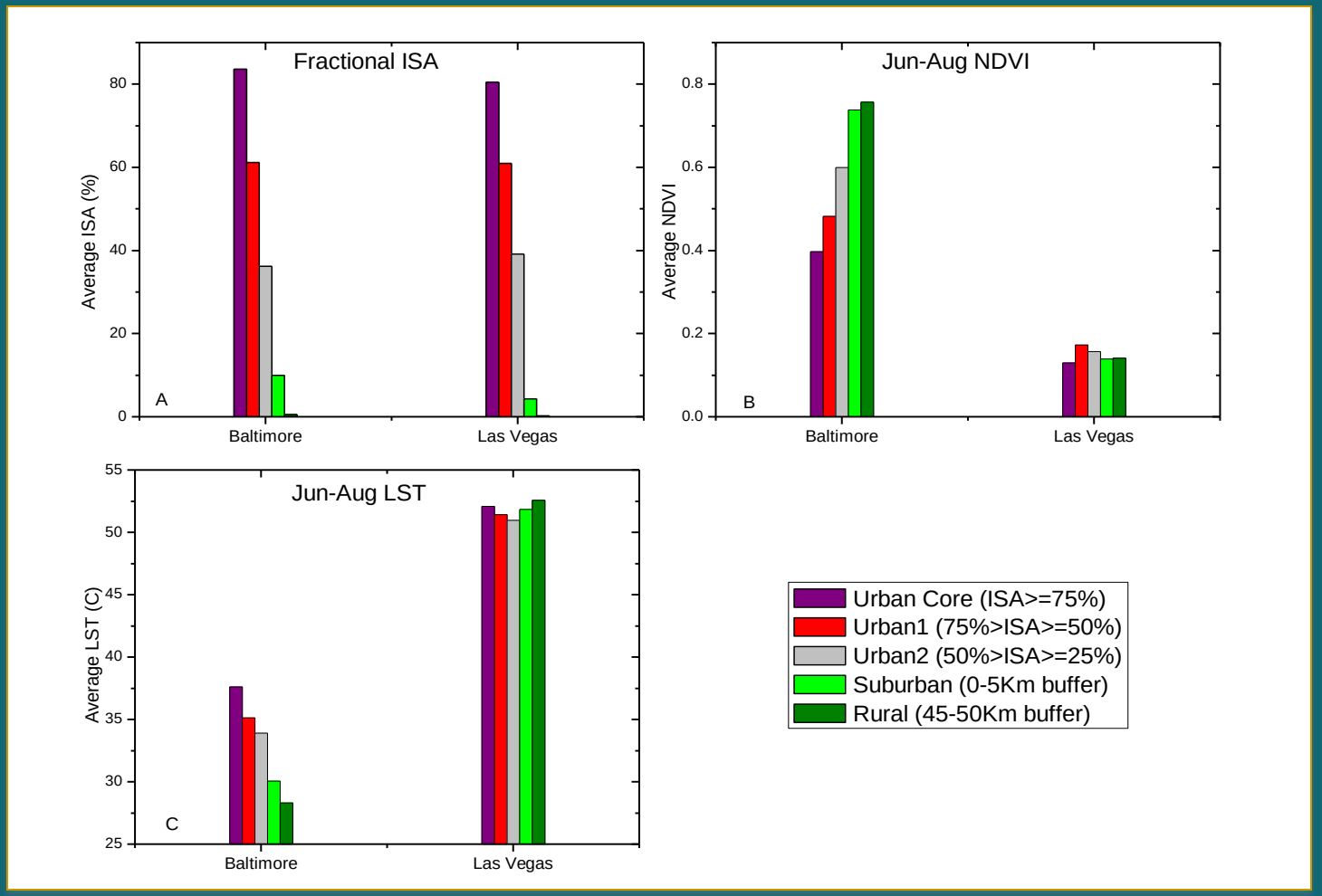
UHI and ecological context



- **UHI=7.1 ºC in cities built in forest**
- **UHI=4.2 ºC in cities built in grass/shrubs**
- **UHI=6.0 ºC in cities built in Mediterranean**
- **UHI=0.25 ºC in cities built in desert**

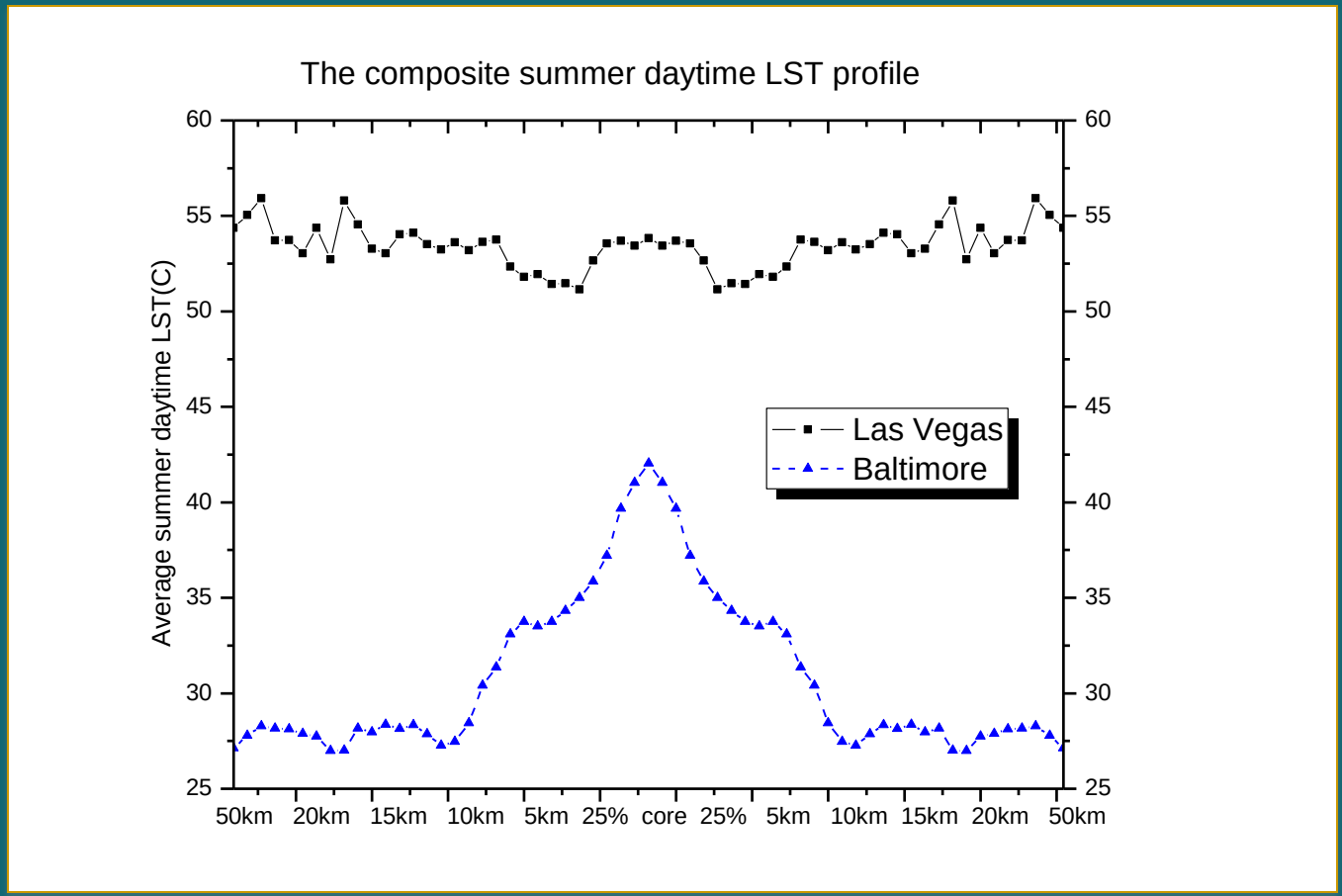
- **The average city size of each group is 159/206/1055/160 km^2**

UHI Baltimore vs. Las Vegas



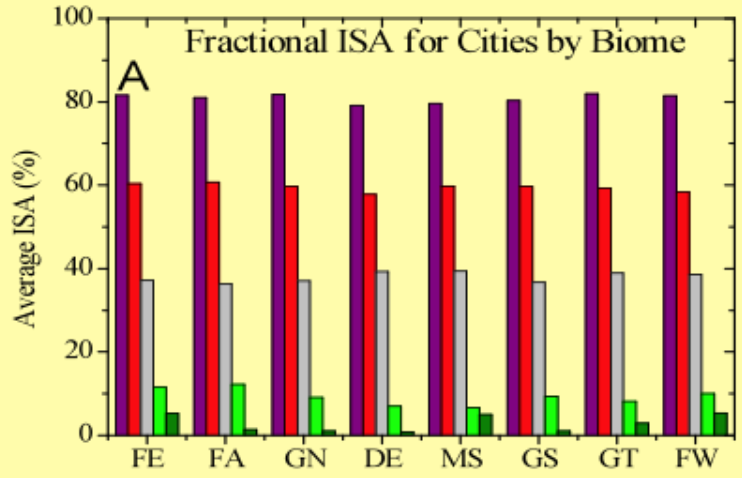
- Baltimore, Maryland, in Notheastern temperate broadleaf and mixed forest
- Las Vegas, Nevada, in desert and xeric shurbland

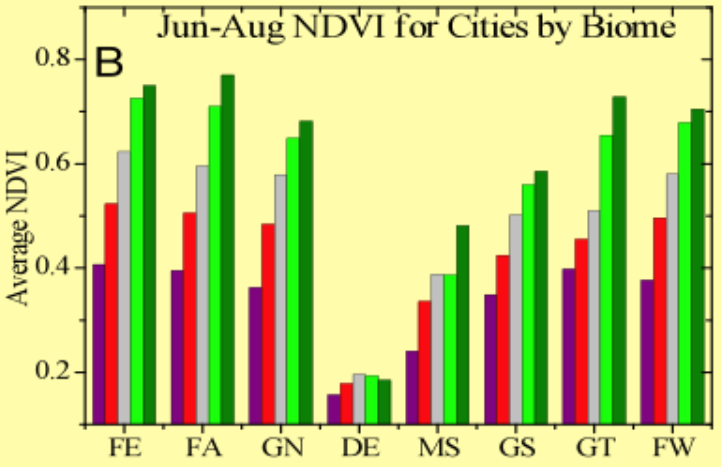
UHI and ecological context: Baltimore vs. Las Vegas

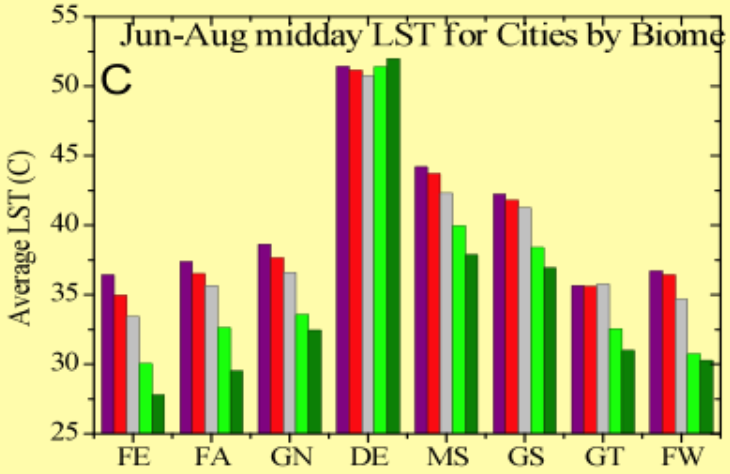


- Composite averaged LST during summer (Jun-Jul-Aug) day time across all urban zones at Baltimore and Las Vegas.

A Biome-Centric View of Remotely Sensed Surface Parameters in US cities





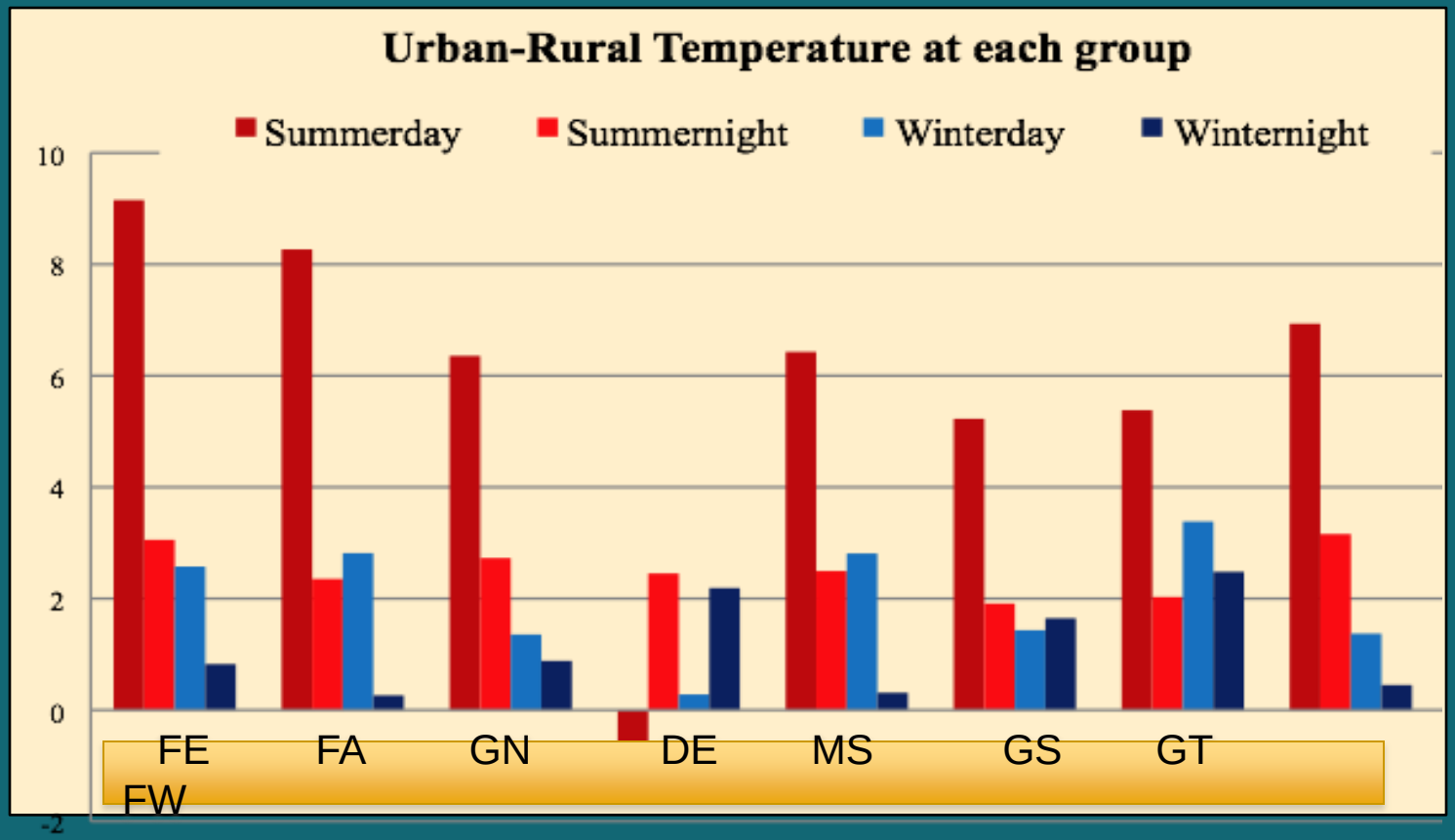


Urban Core (ISA>=75%)
Urban1 (75%>ISA>=50%)
Urban2 (50%>ISA>=25%)
Suburban (0-5Km buffer)
Rural (45-50Km buffer)

Forests – FE, FA, FW
Grass/Shrub – GN, GS, GT
Desert – DE
Mediterranean Shrub/Woodland - MS

Imhoff, Zhang, Wolfe and Bounoua, 2009, RSE 114 (2010)

Urban Heat Islands and Ecological Context
MODIS - Aqua LST (2003-2005)



Summer = Jun-Aug (average LST)
Winter = Dec - Feb (average LST) LST at 1:30 pm local time
Day = 1:30PM Local time
Night = 1:30AM Local time

Forests – FE, FA, FW
Grass/Shrub – GN, GS, GT
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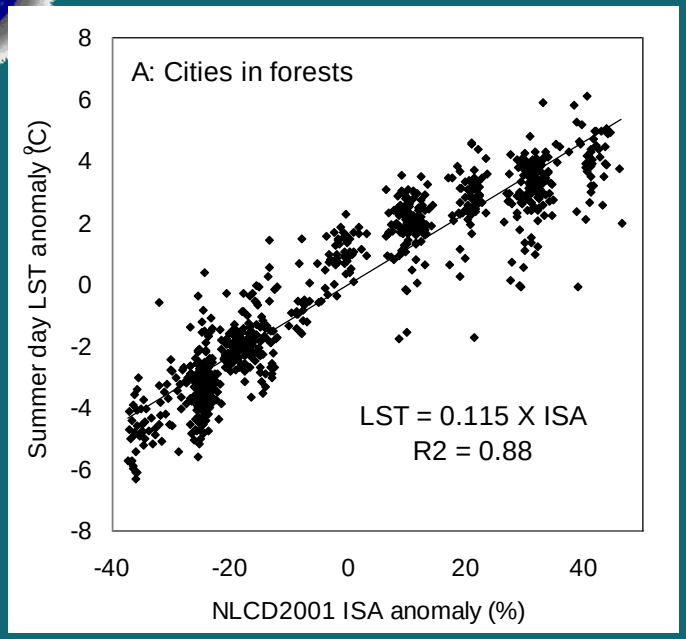
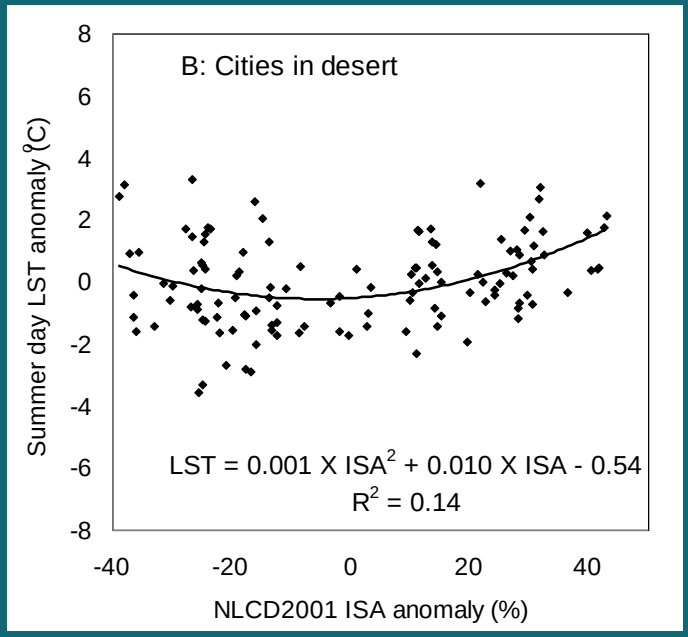
Imhoff, Zhang, Wolfe and Bounoua, 2009, RSE 114 (2010)

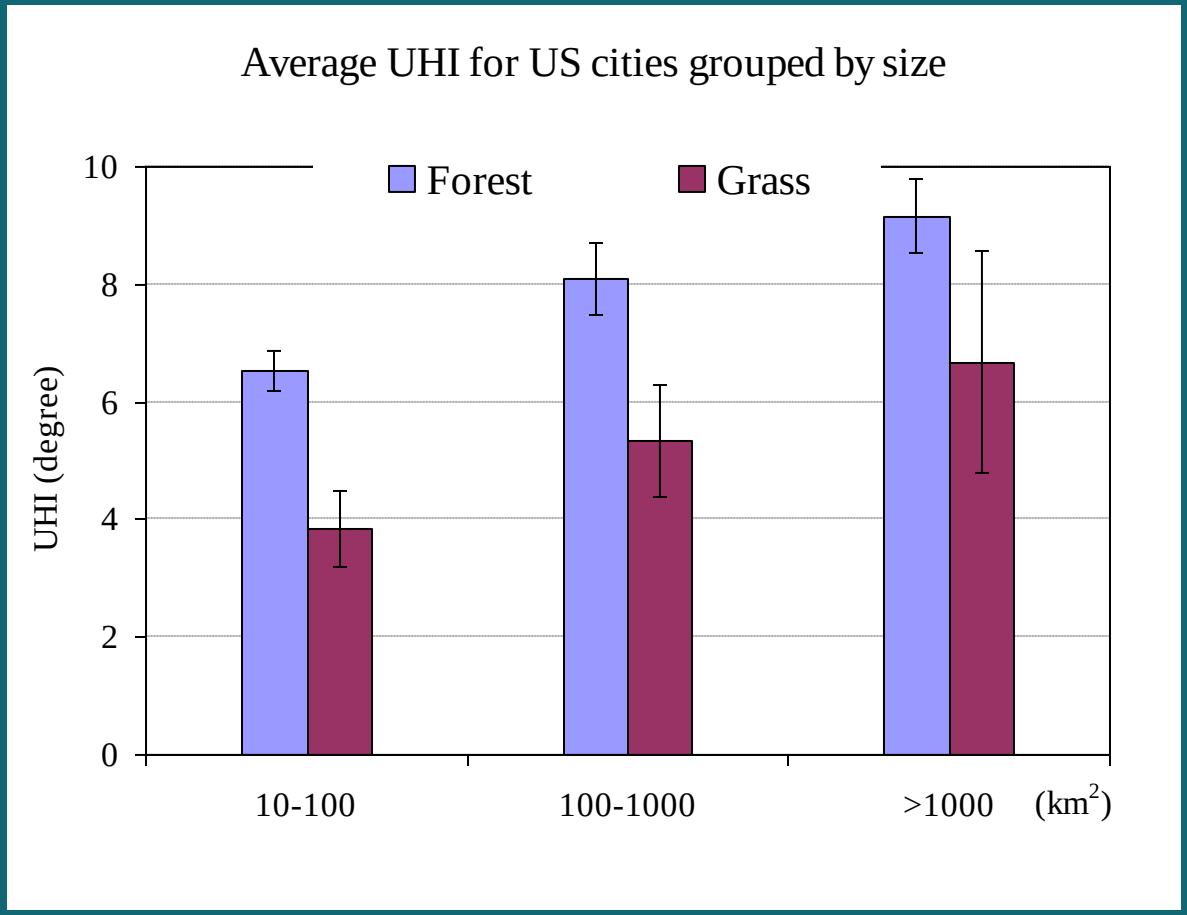
Quantifying the relationship between LST and ISA





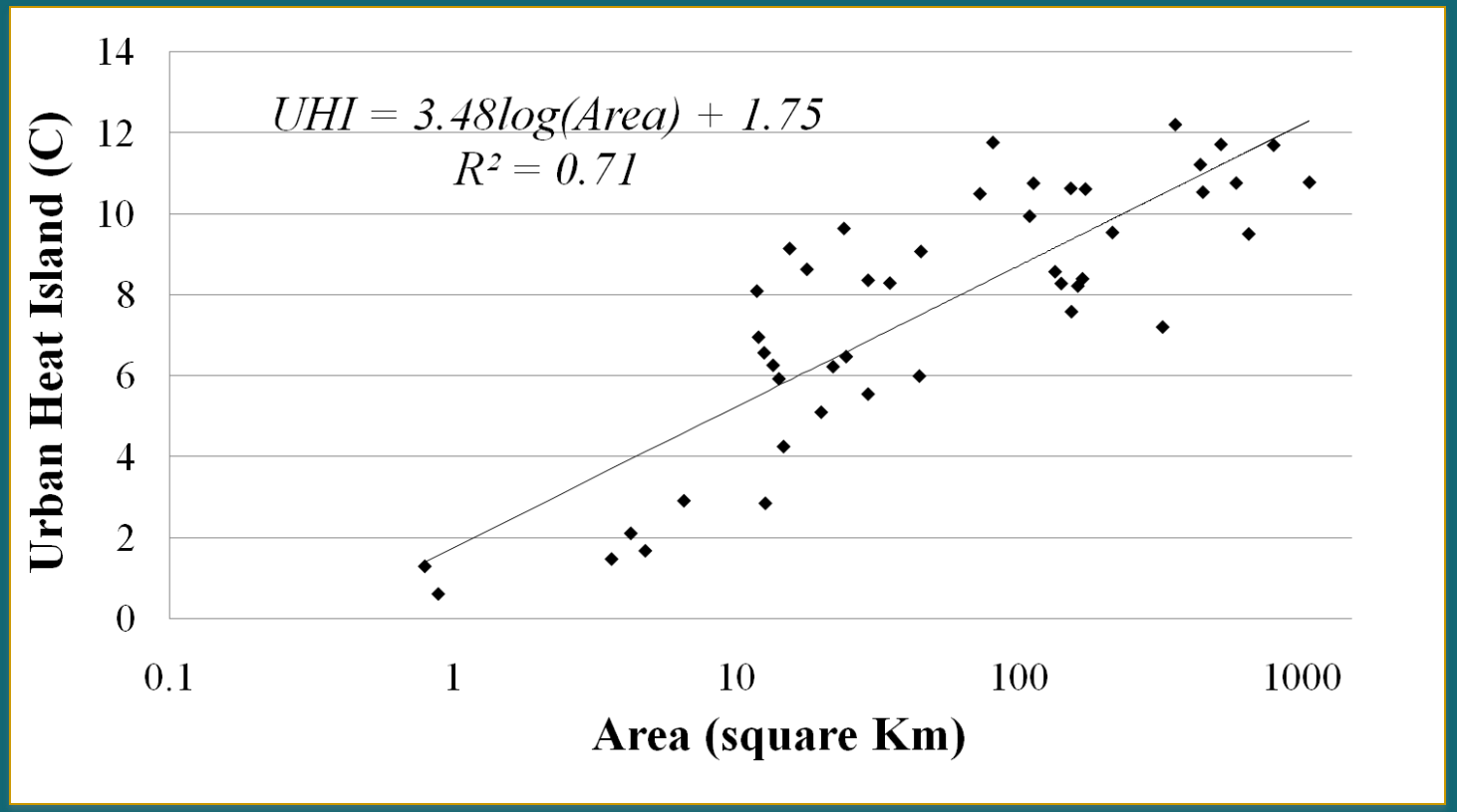
- Variations in ISA explain 88% of the variation in LST for urban areas in forested biomes
- The rate of change in LST as a function of ISA is 11.5% for urban areas in forests, while only 6.9% for those characterized by short vegetations.
- In desert environments, the LST's response to ISA presents is a "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

The magnitude of UHI and size of urban area



- US urban settlements are grouped based on the total contiguous area for each urban polygon defined by 25% ISA threshold
- Average UHI during summer day time is affected by urban size

UHI and urban extent for discrete urban centers in temperate forest (continental US)



Urban extent defined by contiguous area with 25%+ ISA

Conclusions and future directions

- This research highlights significant positive relationships between the UHI magnitude, the ISA, and ecological setting estimated exclusively from remotely sensed observations
- The use of ISA as an estimator of the extent and intensity of urbanization is more objective than population density based methods and can be consistently applied across large areas for inter-comparison of impacts on biophysical processes.
- We will use a combination of satellite and ecological map data to extend the characterization of the UHI response to global urban settlements.
- The uncertainties in ISA outside USA are challenges for future studies as the concept of ISA in the USA does not necessarily transfer to many developing country cities where infrastructure characteristics and properties are often different