EPA Climate Protection Partnership Division
Urban Heat Island Webcast
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Investigation to Mitigate Heat Island Intensity using Models and the National Urban Database and Access Portal Tools (NUDAPT)

Jason Ching
NERL/ORD/USEPA
Research Triangle Park, NC
ching.jason@epa.gov

Presentation Roadmap

1. Issue: Urban Heat Island (UHI) Intensity
2. Urban Meteorology and Air Quality modeling
3. NUDAPT: Introduction and relevance
4. Example: Using NUDAPT to perform UHI mitigation modeling experiments
5. Future Plans, Issues

1. UHI Problem Statement

- Heat Islands are induced in response to urbanization.
- UHI strength increases in complex ways with increasing urbanization and population growth.
- Air quality is reduced and adverse human exposures are exacerbated with increased UHI. Conversely, reducing UHI can mitigate ozone levels.

1. Approaches to Mitigating UHI

- Strategies include repartitioning between surface energy budget components
- Increased efficiency of transportation sector; Decreased energy consumption.

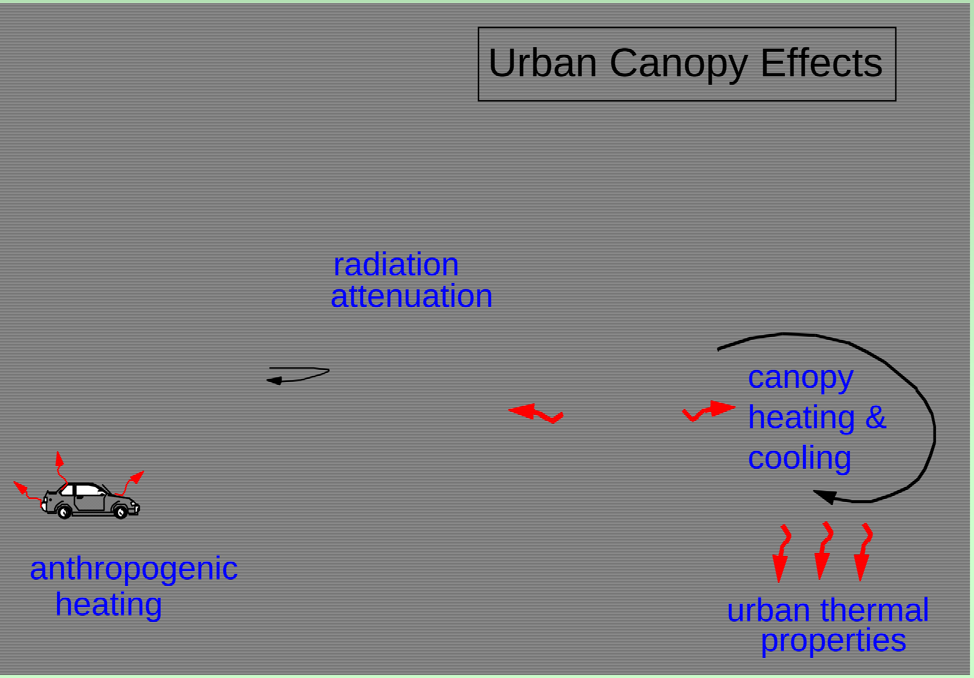
- **Recent advancements in models and data can provide planning tools to explore means to mitigate UHI and other applications**
- **Primary subject of presentation and role of NUDAPT**

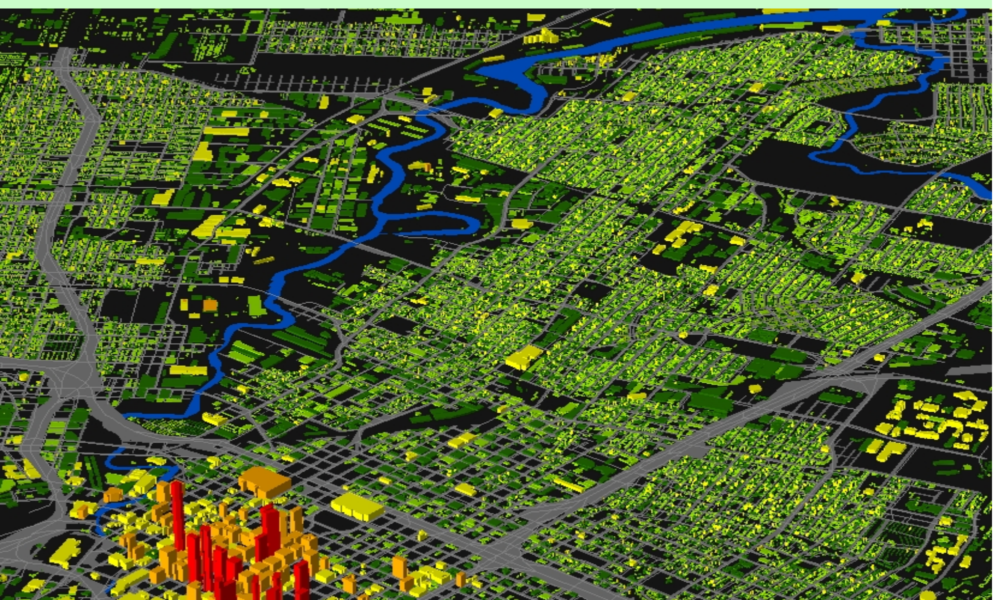
2. MODELING
Urban meteorological and air quality applications

- Meso-Urban scale Meteorological Models
  - **MM5** (**M**esoscale **M**eteorological model Version **5**)
  - **WRF** (**W**eather **R**esearch and **F**orecasting) model

- Dispersion and Air Quality simulation models
  - **AERMOD** (**A**MS/**E**PA **R**egulatory Model Improvement Committee, **AER**MIC **MOD**el
  - **CMAQ** (**C**ommunity **M**ultiscale **A**ir **Q**uality) system

2. CHALLENGE for meso-to-urban scale modeling

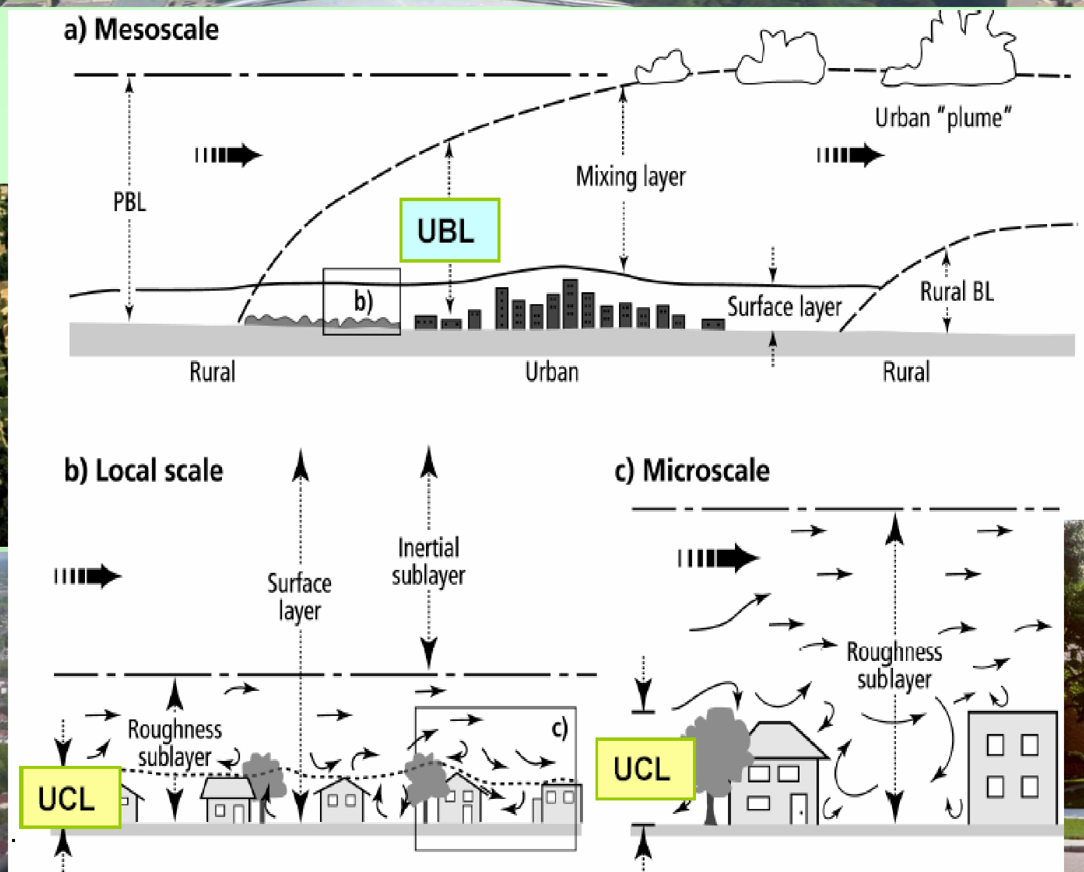




Modeler's need:
To capture the grid average effect of detailed urban features in mesoscale atmospheric models. Typically they have used roughness and displacement lengths according to land usage classifications.

Solution:
Modelers have defined and implemented urban canopy parameterizations into their models (e.g., MM5, WRF, HOTMAC, RAMS, COAMPS…)

2. Models need and can now account for different scales & variations in types, composition of urban land features



Gothenburg

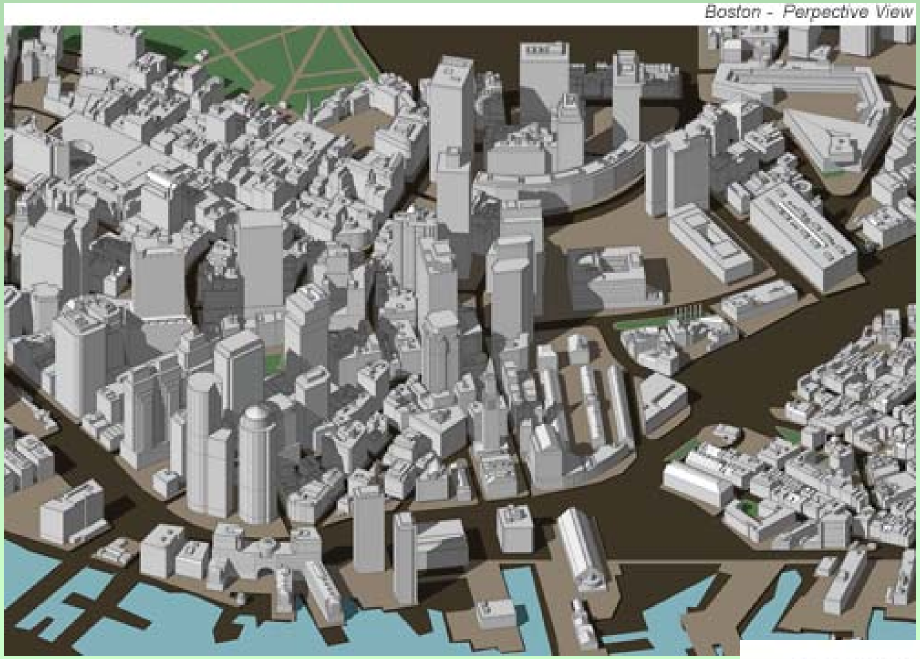
Chicago

2. Introducing drag concepts to relating meso-urban and building scale features

Meso-Urban: Model produces single meteorology profile applicable to each grid cell. Results influenced by the presence and aggregated effects of buildings.

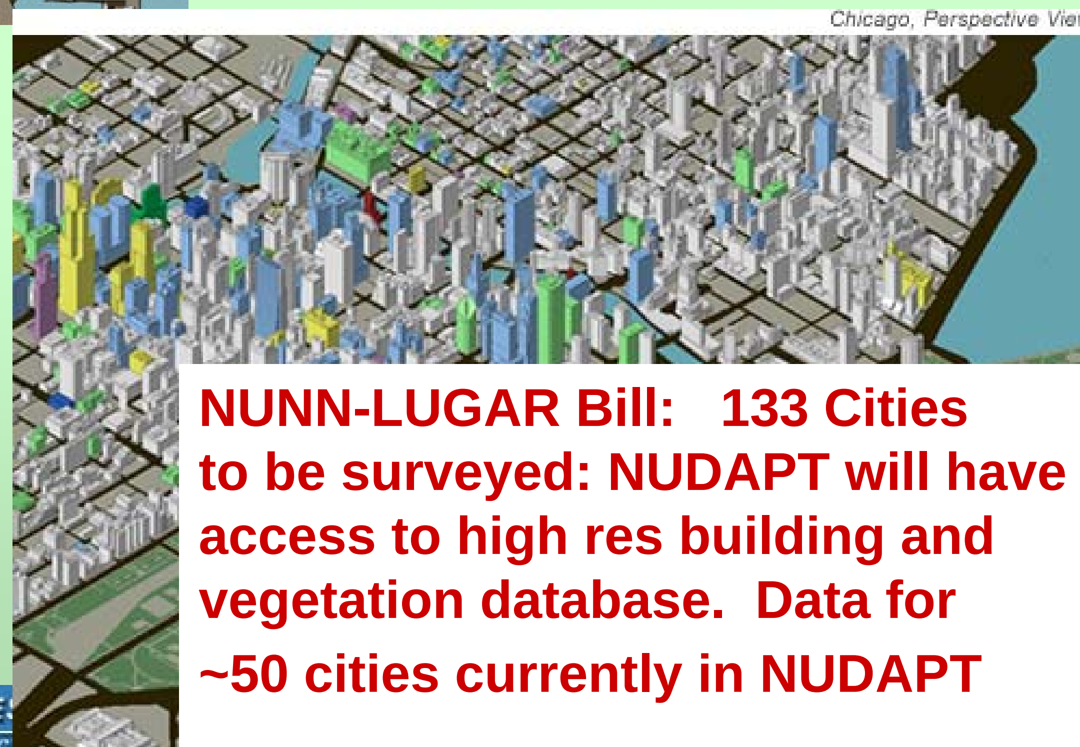
Building scale: Intra-cell flow fields will be highly variable (horizontally and vertically), influenced by the individual buildings.

Methodology: Define, compute and introduce canopy parameterizations such as frontal area density, roof area density, roof to frontal index, height to width ratios, and similar ones for vegetation into models.



We have the technology and means for obtaining building data at high resolution; such data and ancillary data are becoming increasingly more available for our major cities

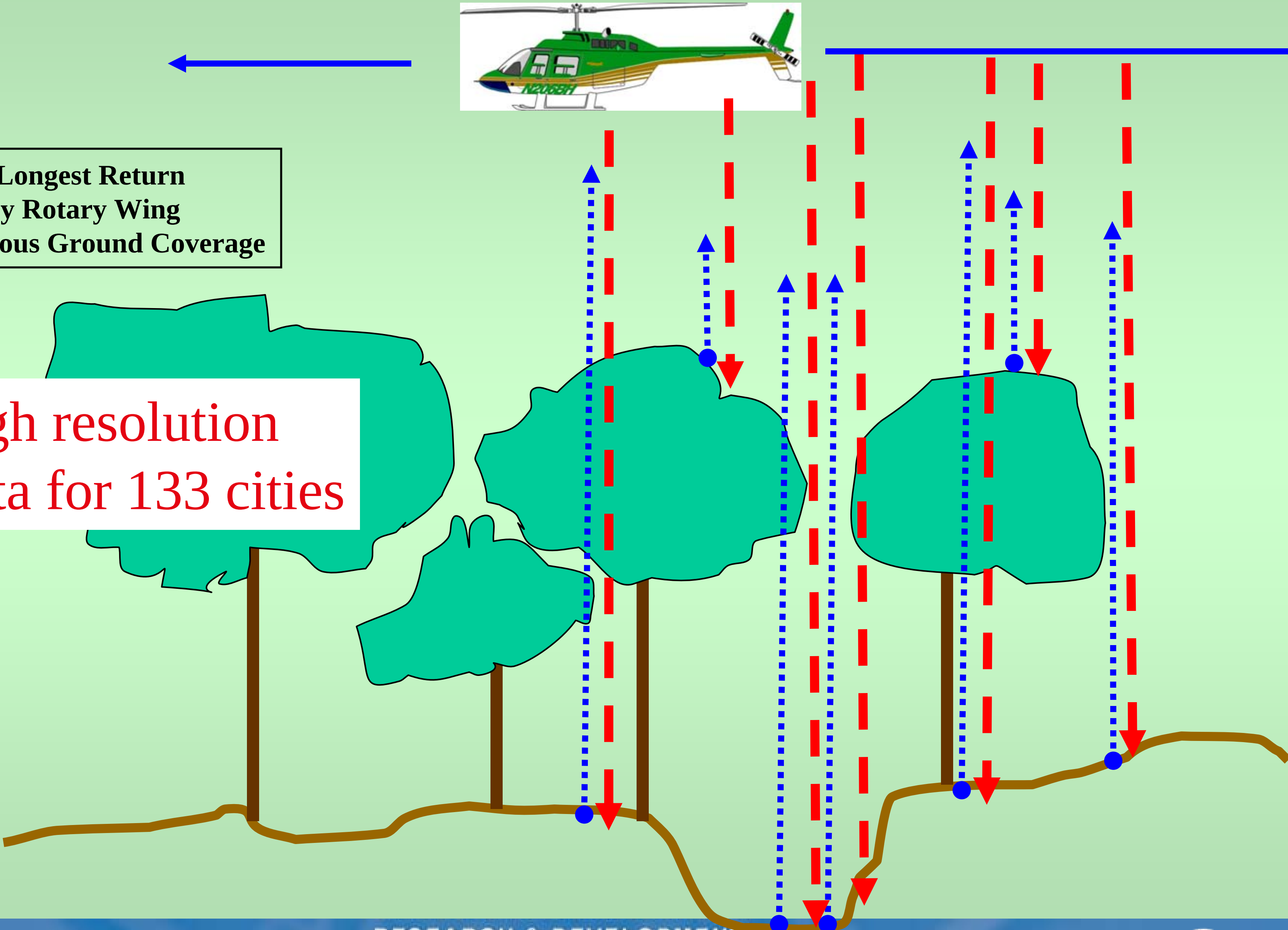
High resolution urban morphological data can be derived from lidar mapping and photogrammetric techniques



NUNN-LUGAR Bill: 133 Cities to be surveyed: NUDAPT will have access to high res building and vegetation database. Data for ~50 cities currently in NUDAPT

2. LIDAR Profiling to obtain building and vegetation data

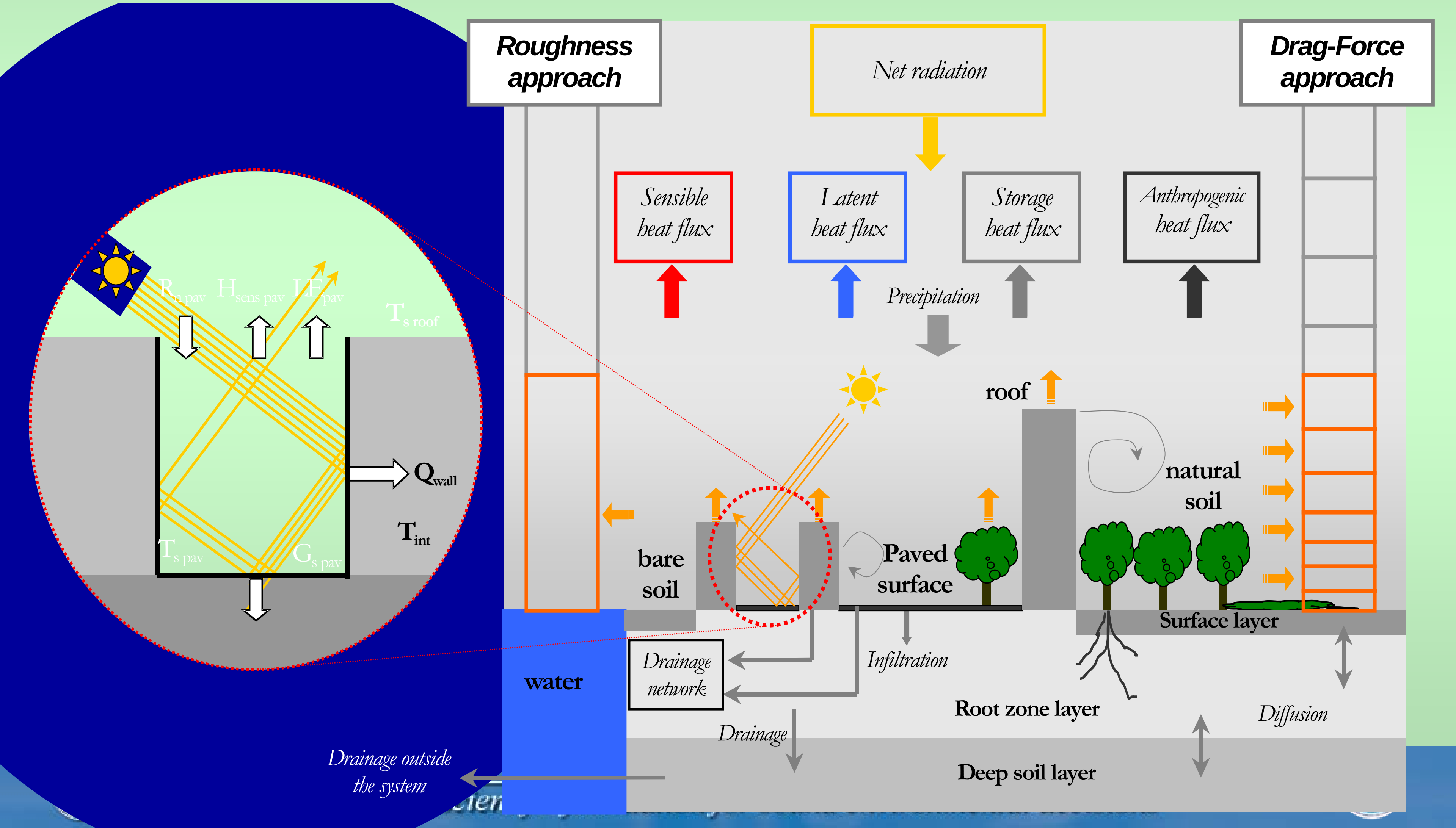
*** Record Longest Return**
*** Normally Rotary Wing**
*** Continuous Ground Coverage**



High resolution
Data for 133 cities

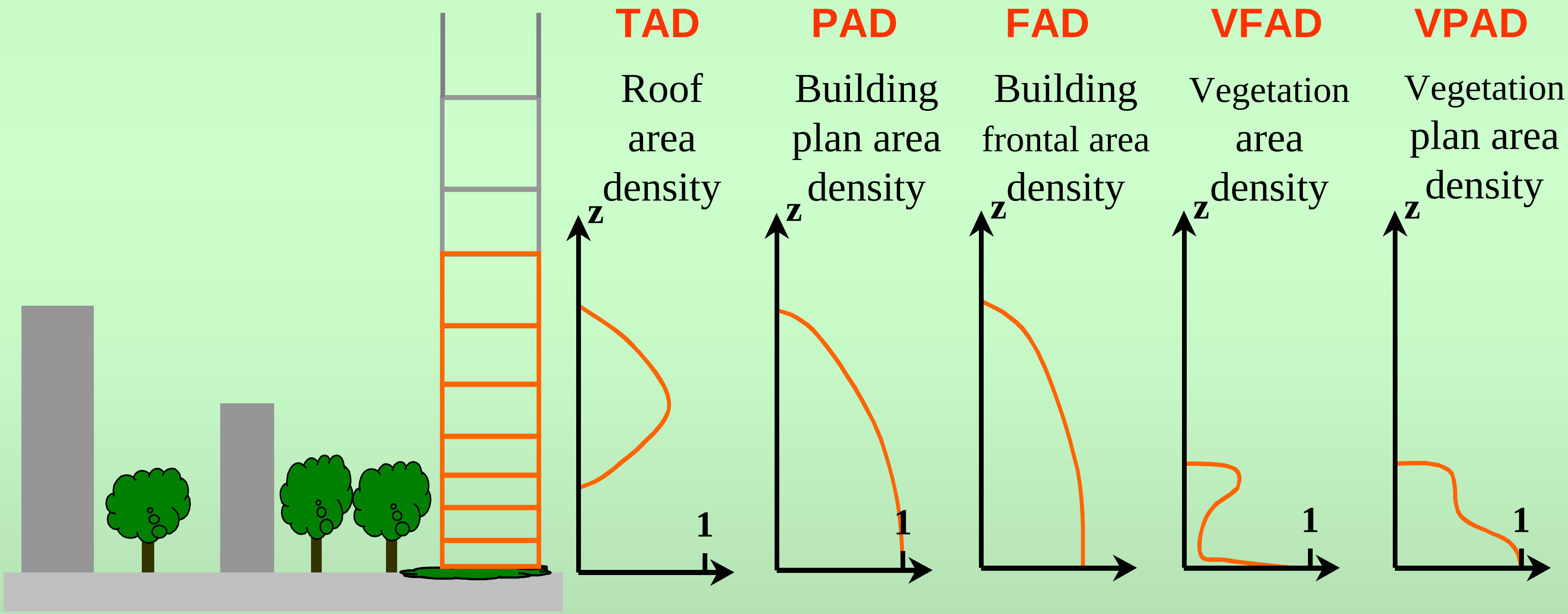
2. Introducing urban canopy features into MM5

- o Building, vegetation, street canyons, paved areas now included
- o Fuller accounting for radiative trapping by street canyons
- o Additional canopy layers account for drag by various obstacles

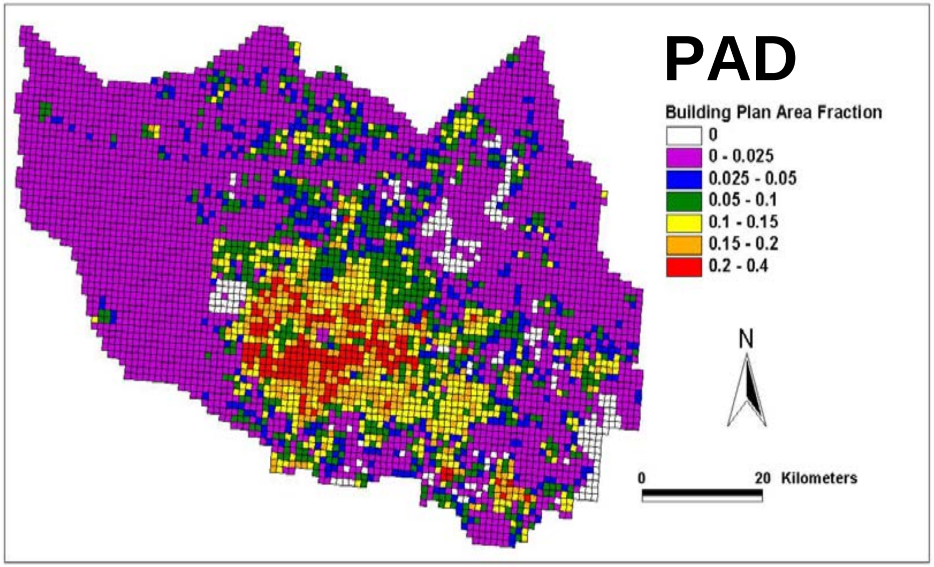


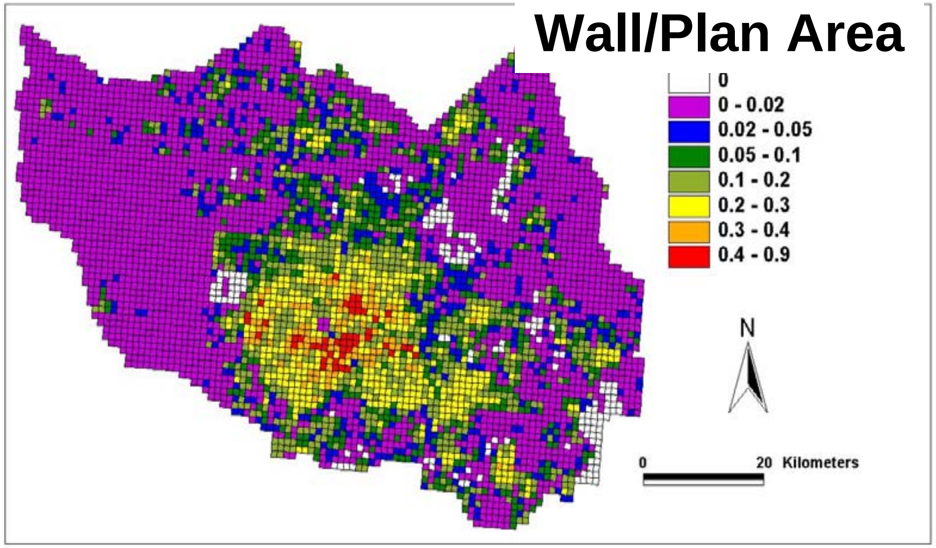
2. Implementation of canopy concepts and urban morphology parameters for improved modeling

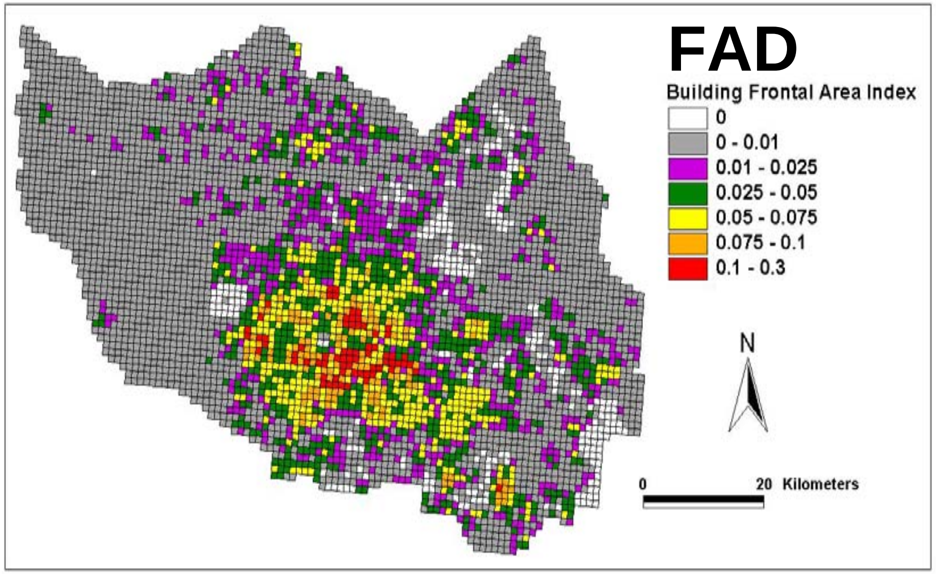
The knowledge of the vertical and horizontal distribution of the different urban land cover modes is necessary.

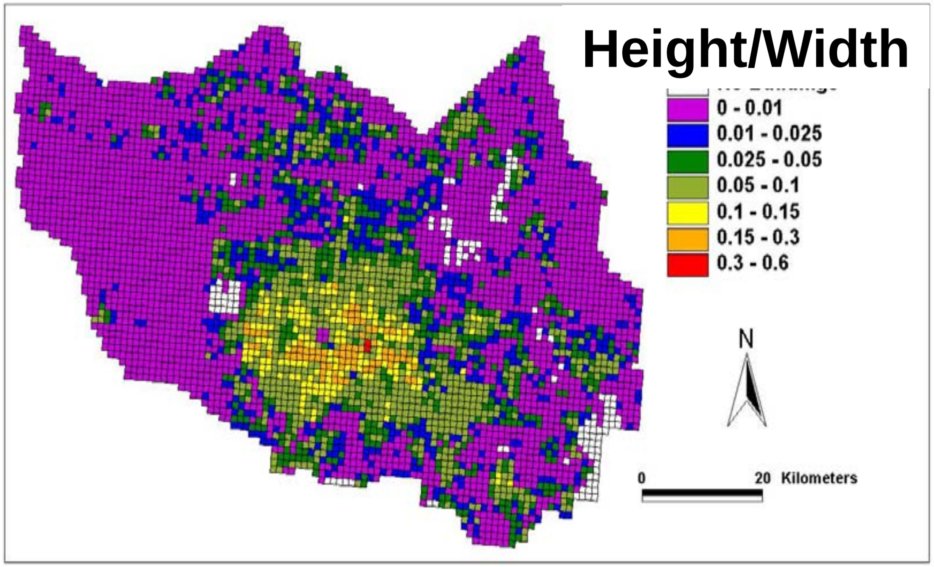


2. Selected Urban Canopy Parameters per 1 km^2 cells for Harris County, TX; NOTE! Unique combination of UCPs/cell









3. NUDAPT: strategic tool kit for advanced urban model implementation and applications

- Advanced urban modeling needs new and sophisticated datasets. In 2005, EPA supported our proposal to develop a community framework urban modeler’s database we call National Urban Database and Access Portal Tools or NUDAPT.
- Poll and Workshops: Overwhelming support from AMS, OFCM for this idea and the concepts underlying such a database.
- Implementation of this (two year) Project was made possible with strong support and significant contributions from core group of 19 Collaborators
- **Today we report status and suggested UHI applications based on this Prototype.**

3. NUDAPT supports more robust model applications. It can make a significant difference!

- **Model sensitivity studies show significant response to improved urban modeling e.g., air quality**
- **Advanced models provide bases for urban design, investigations of urban heat island mitigation**
- **Resource capable of supporting a variety of modeling systems**
- **Database can be extended to incorporate additional information such as population and anthropogenic heating for custom applications**
- **Addresses applications for homeland security needs, and air quality/human exposure assessments.**

3. Prototype Implementation The "NUDAPT" Framework

- **Urban modeling is its major focus**
- **Adopts community modeling system paradigm with Portal technology**
- **Database consists of primary data and derived parameters**
  - **High resolution geospatial data: repository or links (133 cities in USA)**
  - **Appropriate and complete set of parameterizations at urban grid scales**
  - **Ancillary data (to facilitate applications; curently includes gridded day and night population and anthropogenic heating data)**
- **Includes capability to regrid data for customizing data according to size and map projection of users.**
- **Houston serves as developmental prototype**

3. UCPs in NUDAPT (& growing!)

MM5 Meteorological model

- Mean and standard deviation of building and vegetation height
- Plan-area weighted mean building and vegetation height
- Building height histograms
- Plan area fraction and frontal area index at ground level
- Plan area density, top area density, and frontal area density
- Complete aspect ratio
- Building area ratio
- Building height-to-width ratio
- Sky view factor at ground level and as a function of height
- Aerodynamic roughness length and displacement height (Raupach, Macdonald, Bottema) coefficients
- Mean orientation of streets
- Surface fraction of vegetation, roads, rooftops, water and impervious area, directly connected impervious area, albedo and building material using remote sensing

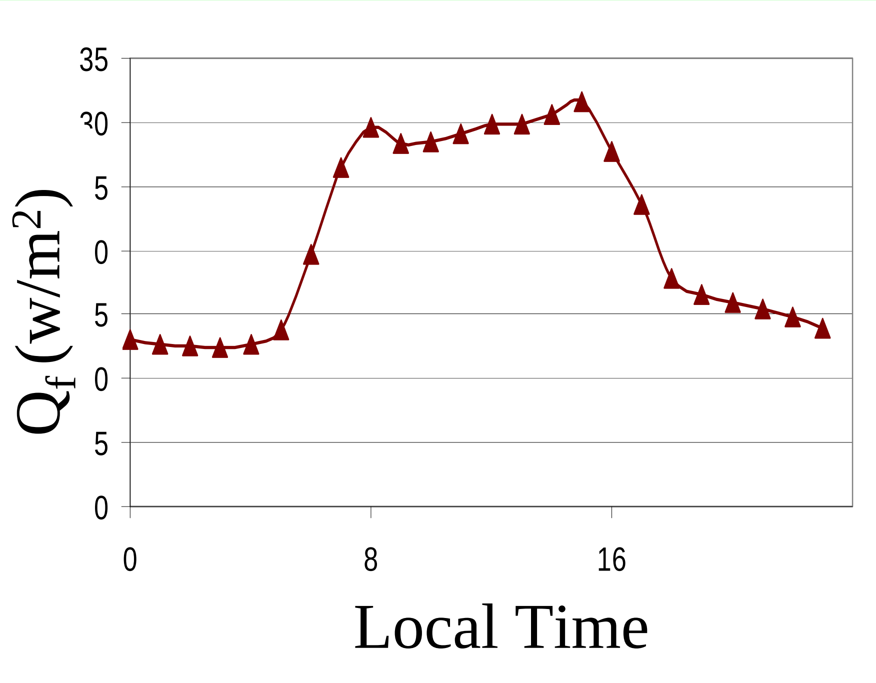
WRF Next generation model

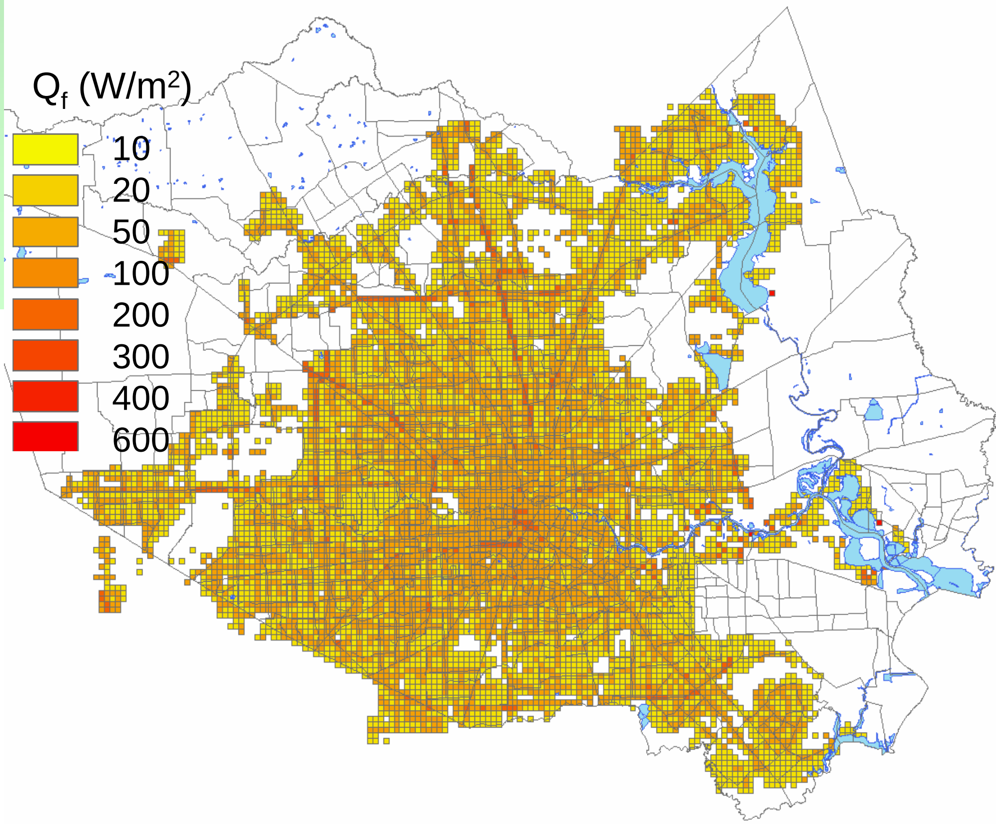
- Urban fraction
- Building height, ZR
- Roughness for momentum above the urban canopy layer, ZoC
- Roughness for heat above the urban canopy layer ZoHC
- Zero-displacement height above the urban canopy layer, ZDC
- Percentage of urban canopy, PUC
- Sky view factor, SVF
- Building coverage ratio (roof area ratio), R
- Normalized building height, HGT
- Drag coefficient by buildings, CDS
- Buildings volumetric parameter, AS
- Anthropogenic heat, AH
- Heat capacity of the roof, wall, and road
- Heat conductivity of the roof, wall, and road
- Albedo of the roof, wall, and road
- Emissivity of the roof, wall, and road
- Roughness length for momentum of the roof, wall, and road
- Roughness length for heat of the roof, wall, and road

4. Gridded Anthropogenic Heating (1 km grids)

(Courtesy of David Sailor, NUDAPT Collaborator)

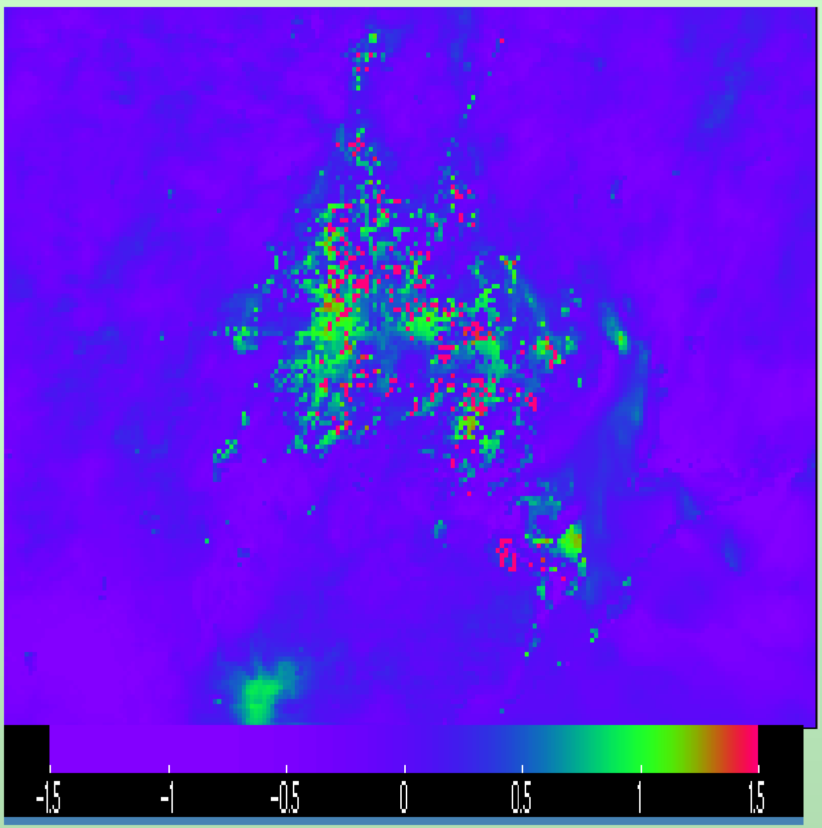
Another sensitivity variable in NUDAPT that can be examined using advanced urbanized models to explore and develop UHI mitigation strategy options.



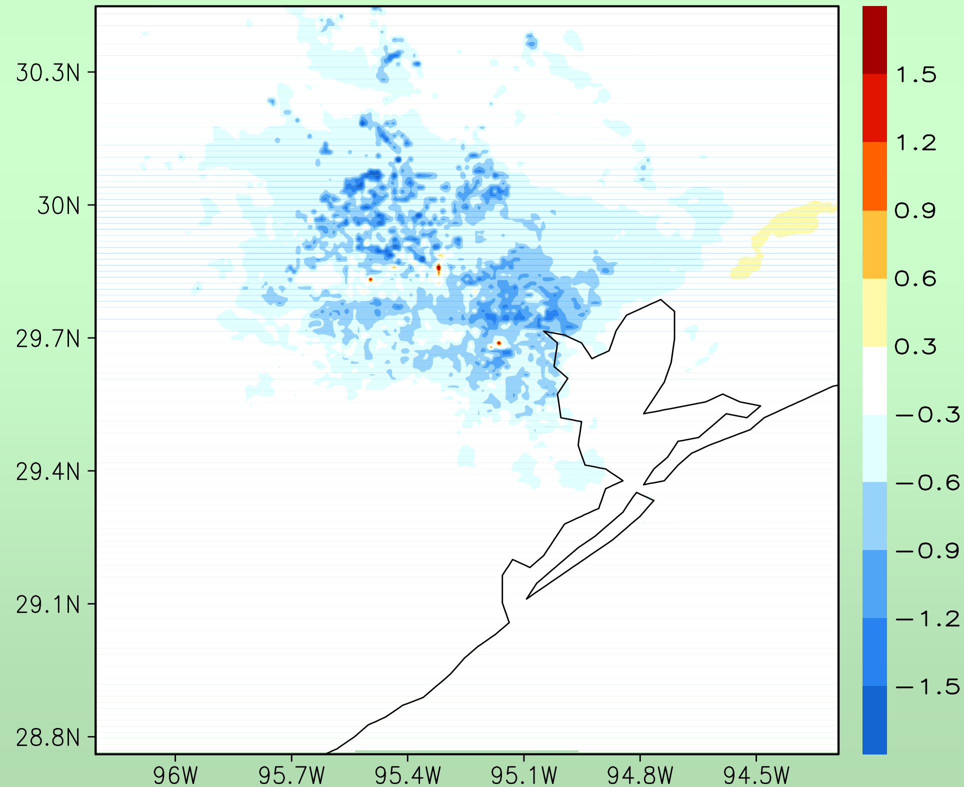


Sensitivity Study based on WRF-Noah UCM 2-m Temperature differences (ºK)

(a) MODIS_UCM – MODIS_Noah
0300 UTC Aug 24, 2006



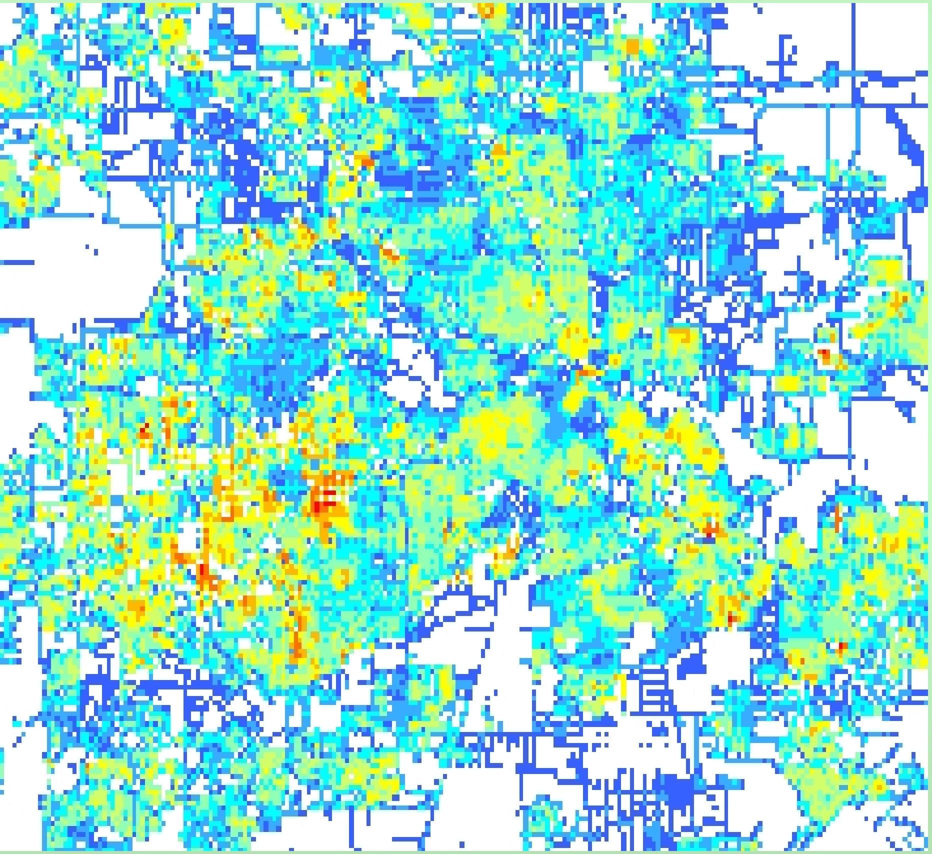
(b) Anthropogenic heating data using NUDAPT – Default standard table-lookup
0600UTC Aug 31, 2000



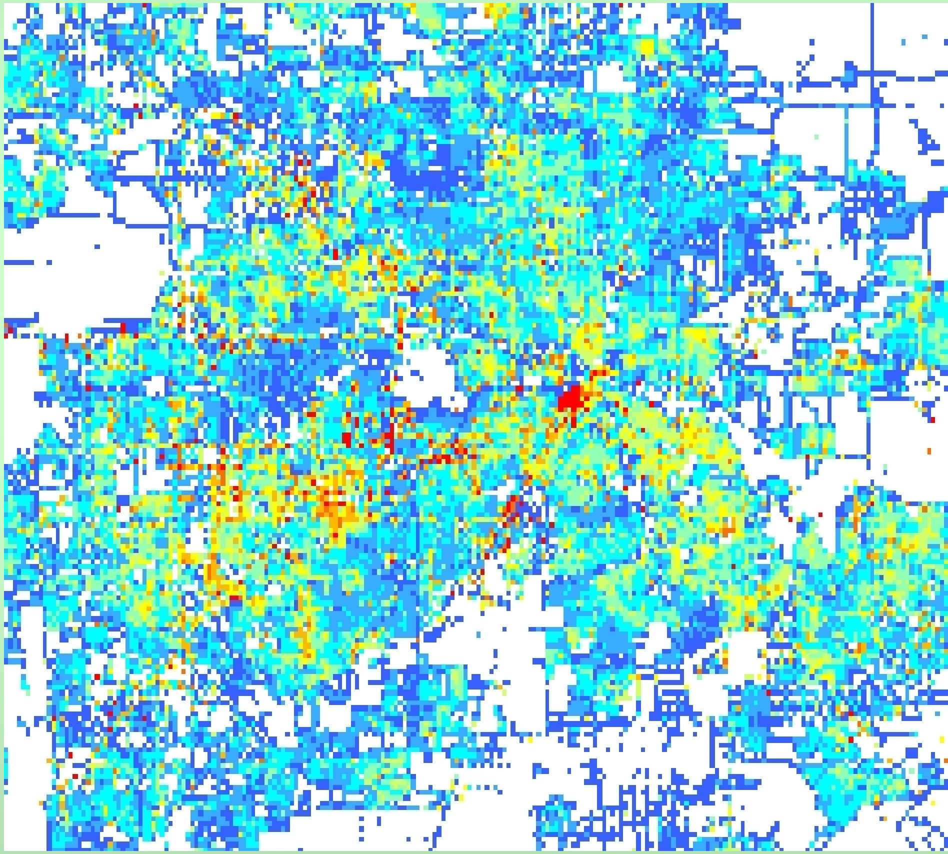
250m gridded population for central Houston, Texas

Courtesy of McPherson and Brown (2007)

Night time Population

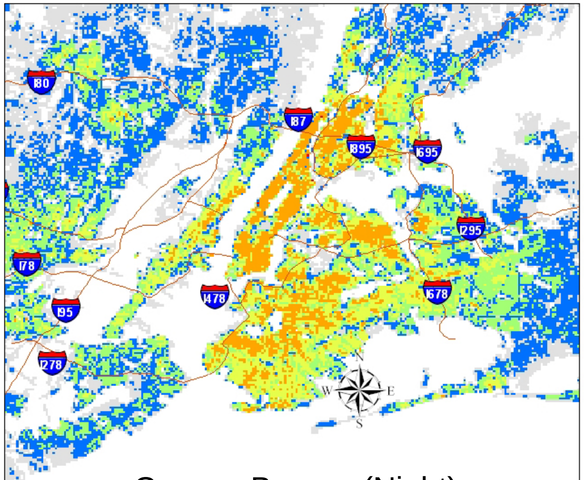


Daytime Population

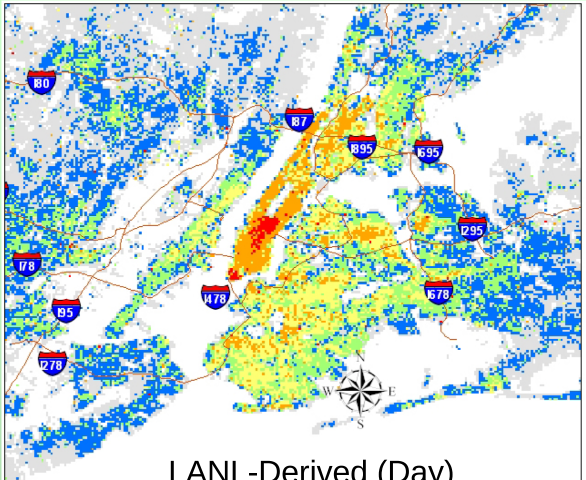


Population Courtesy of McPherson and Brown (2007)

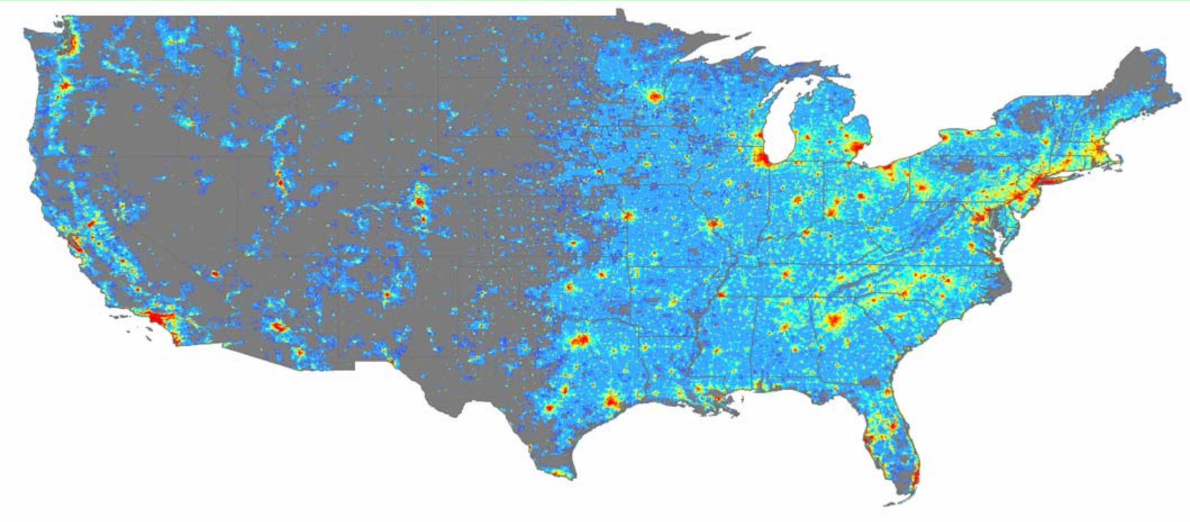
- **Options:** Census, LANL, other government agencies
- **Prototype:** LANL Day/Night population national coverage
- **Future:** LANL database including indoor/outdoor exchange rate?



Census Bureau (Night)



LANL-Derived (Day)



3. Custom Collaborations

Modeling Systems

MM5
WRF
COAMPS
Canadian
Army scale

Urban Prototypes

Houston
Phoenix
Atlanta

EU Megacity?

Data and Derived Products

High Resolution data
UCPs- Model Customized
Day-night gridded Populations
Gridded Anthropogenic Heat

Applications, Assessments

UHI Studies

Exposure Assessments

Urban Planning

Specialized AERMOD for urban

4. Urban Heat Island mitigation study

Mitigation of urban heat islands can help:

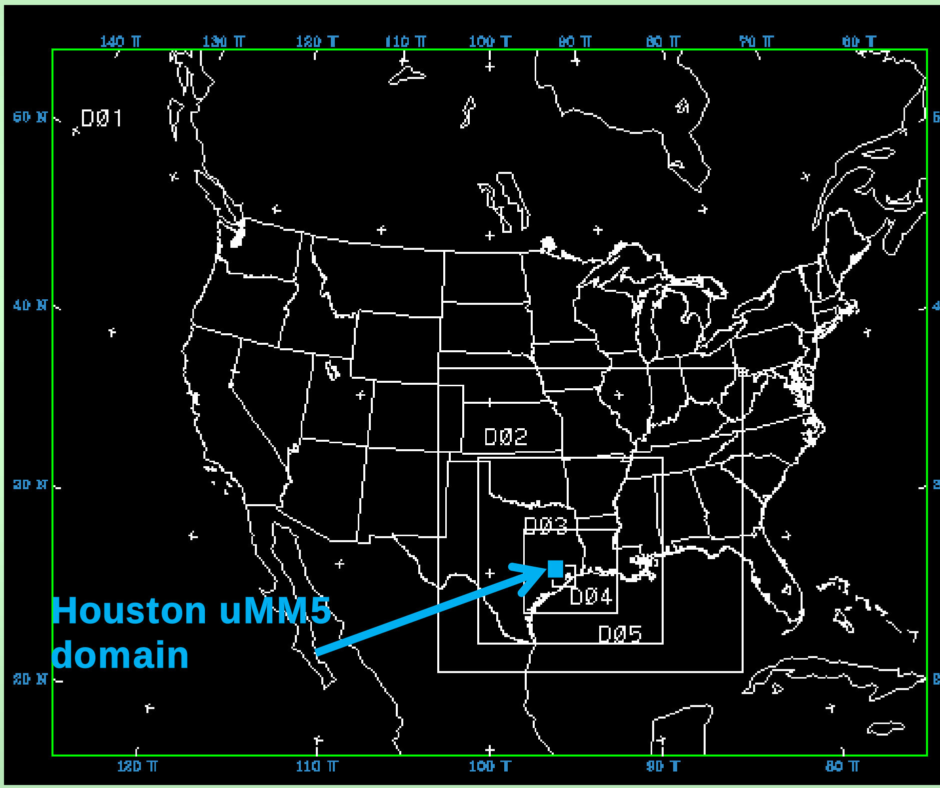
- **Reduce cooling energy use; Reduce emissions from power plants**
- **Reduce rates of emissions (NOx, VOC, CO2, ..) from biogenic and anthropogenic sources**
- **Slow down the photochemical production and / or accumulation of ground-level / tropospheric ozone**
- **Reduce impact of heat and heat-pollution waves; reduce mortality**
- **Impact convective precipitation and heat-pollution plumes**
- **Improve air quality, visibility**

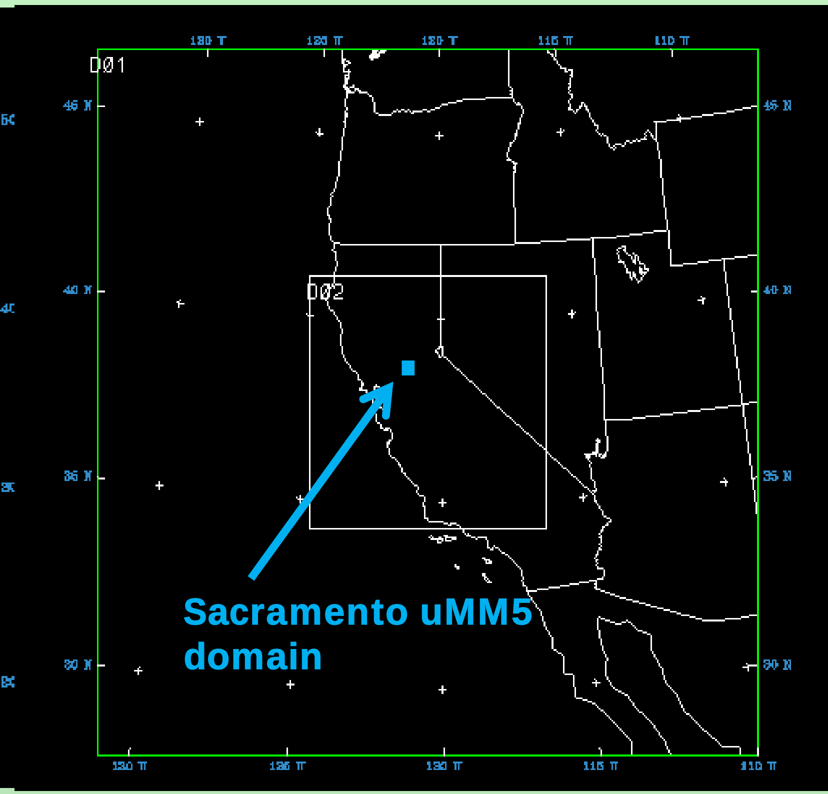
Heat islands can be mitigated via:

- **Increased albedo and / or effective urban albedo (attn: > 0.37 μm)**
- **Increased canopy cover (attn: isoprene / terpene emissions)**
- **Decreased anthropogenic heat flux**
- **Managing storage heat flux, thermal mass, materials properties**
- **Managing moisture and runoff, impervious surface area**
- **Controlling urban geometry (solar access and implications)**

4. Examples of uMM5 applications:

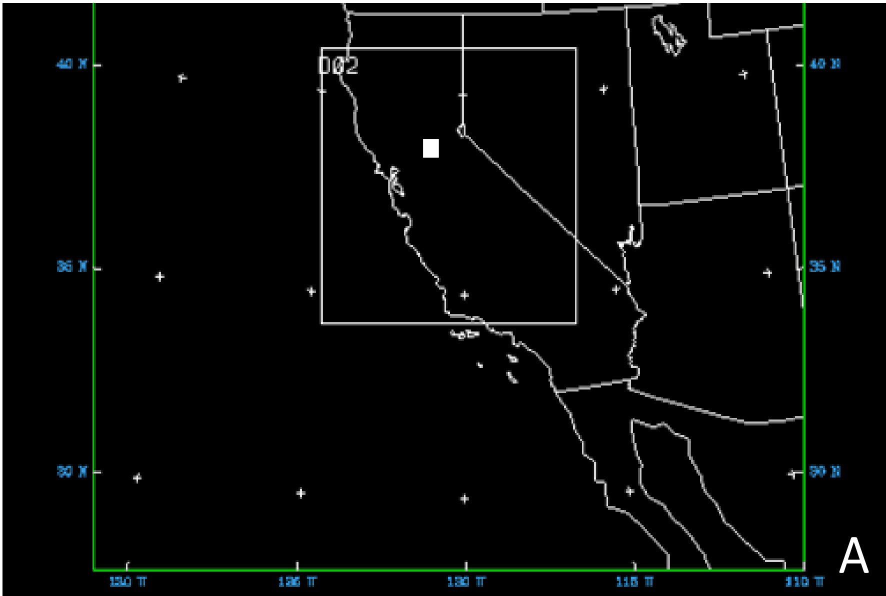
Houston-Galveston Texas and
California Urban Heat Island mitigation study
H. Taha, NUDAPT collaborator

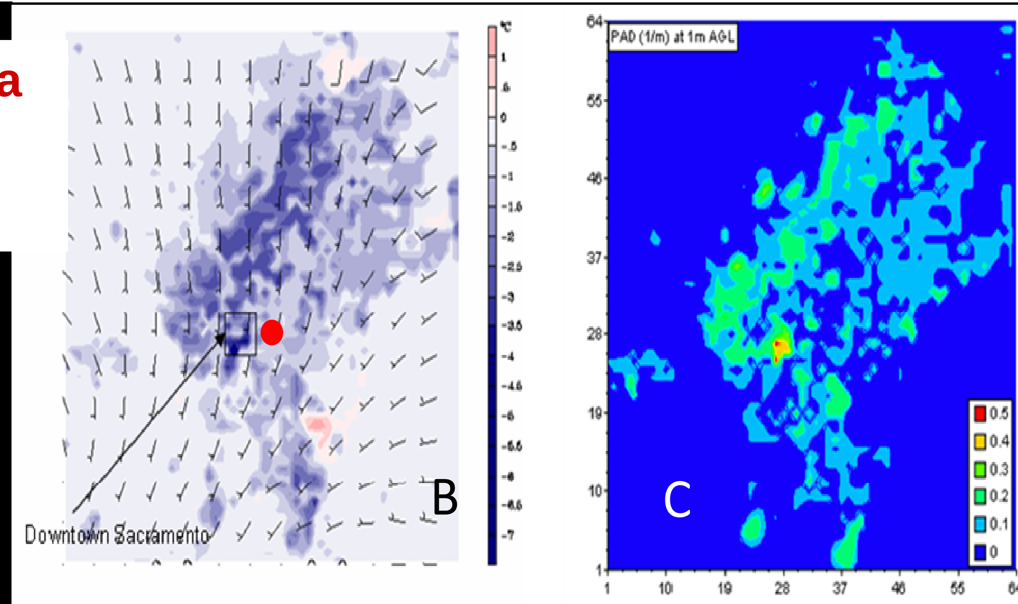


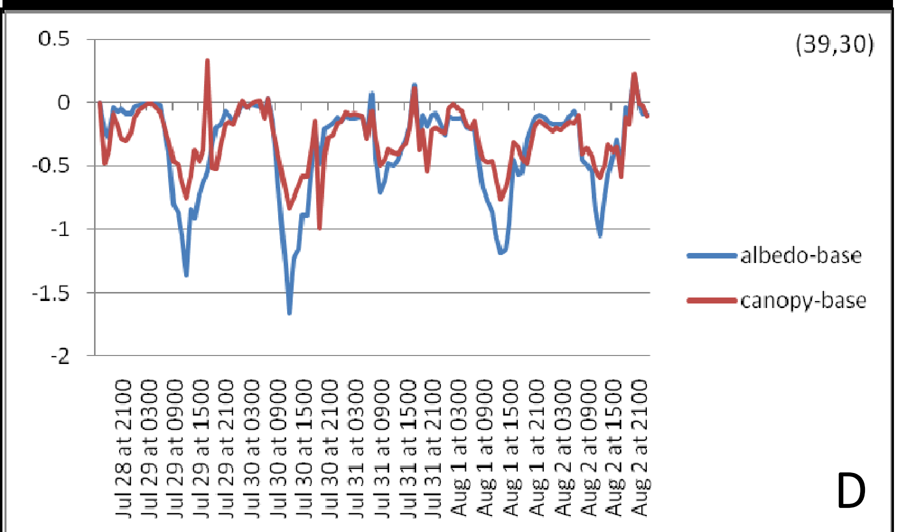


ALTOSTRATUS

Simulating UHI and mitigation potentia (cooling) of the air and at the surface as a result of increased urban albedo.







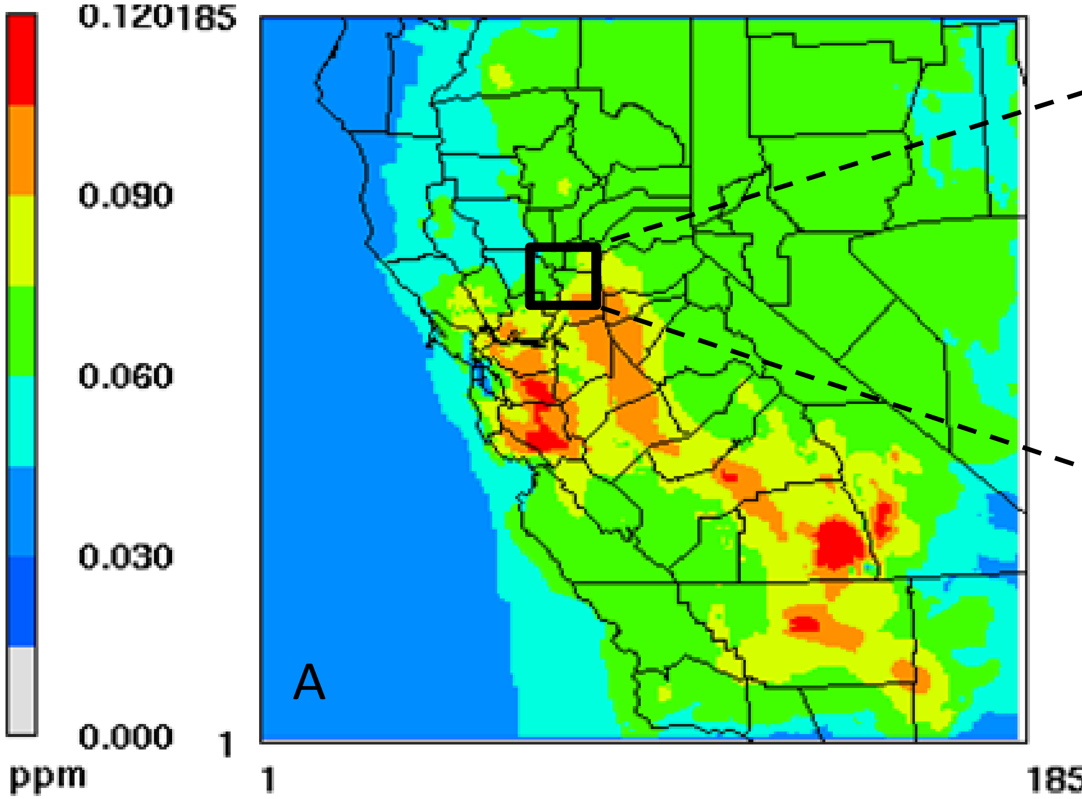
A: Mesoscale (MM5; 12 and 4km) and meso-urban (uMM5; 1km) meteorological simulation domains (Taha 2008a). The small white rectangle indicates the Sacramento-area uMM5 modeling domain which is enlarged and shown in figures B and C.

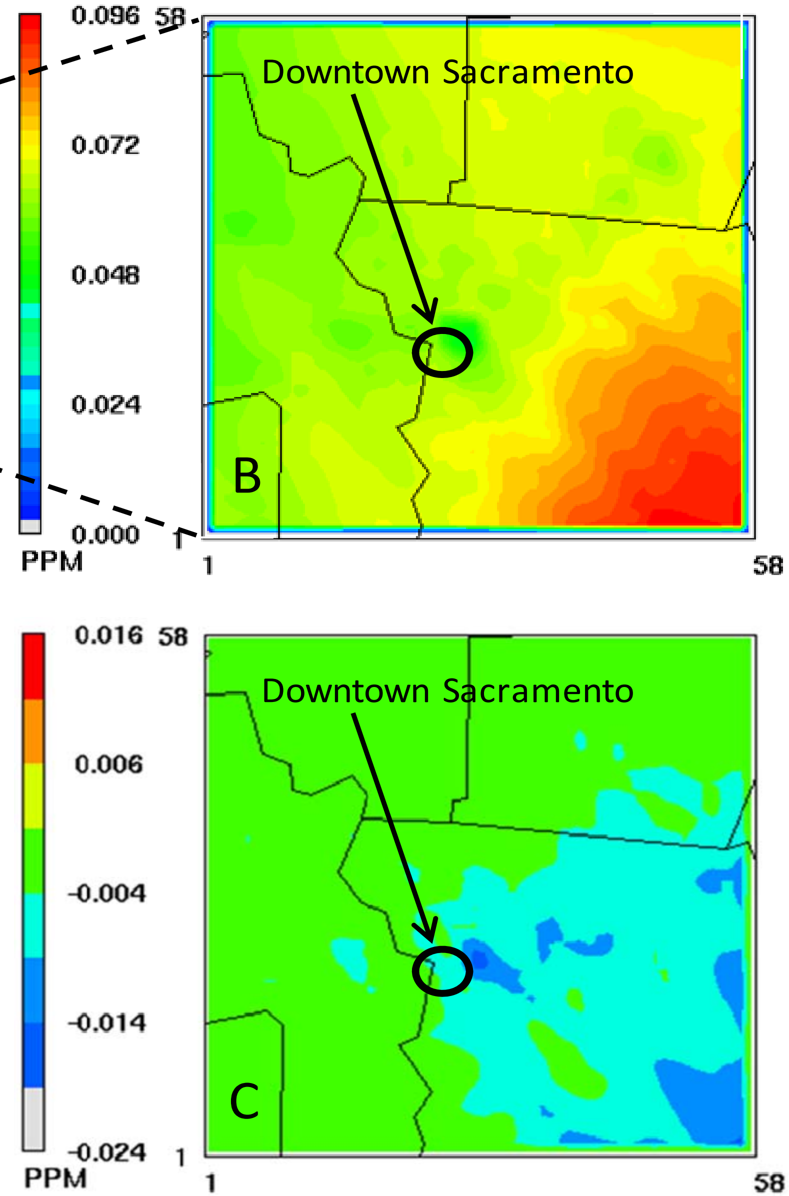
B: Simulated surface temperature change (C^{o}) as a result of increased urban albedo in Sacramento. Decrease in surface temperature reaches up to 7^{o}C in and near the Downtown area (square inset). Example is for 1300 PDT, July 31.

C: Building plan-area density function, PAD (1/m), at 1m AGL for the Sacramento area. This figure is included to show a near perfect correspondence between decrease in surface temperature (figure B) and change in roof albedo (as indicated via PAD).

D: Change in 2m air temperature July 28 through August 2 at an arbitrary point (red dot in figure B) as a result of increased urban albedo (blue line) and urban forest (red line).

4. Simulating changes in ozone to UHI reduction scenarios





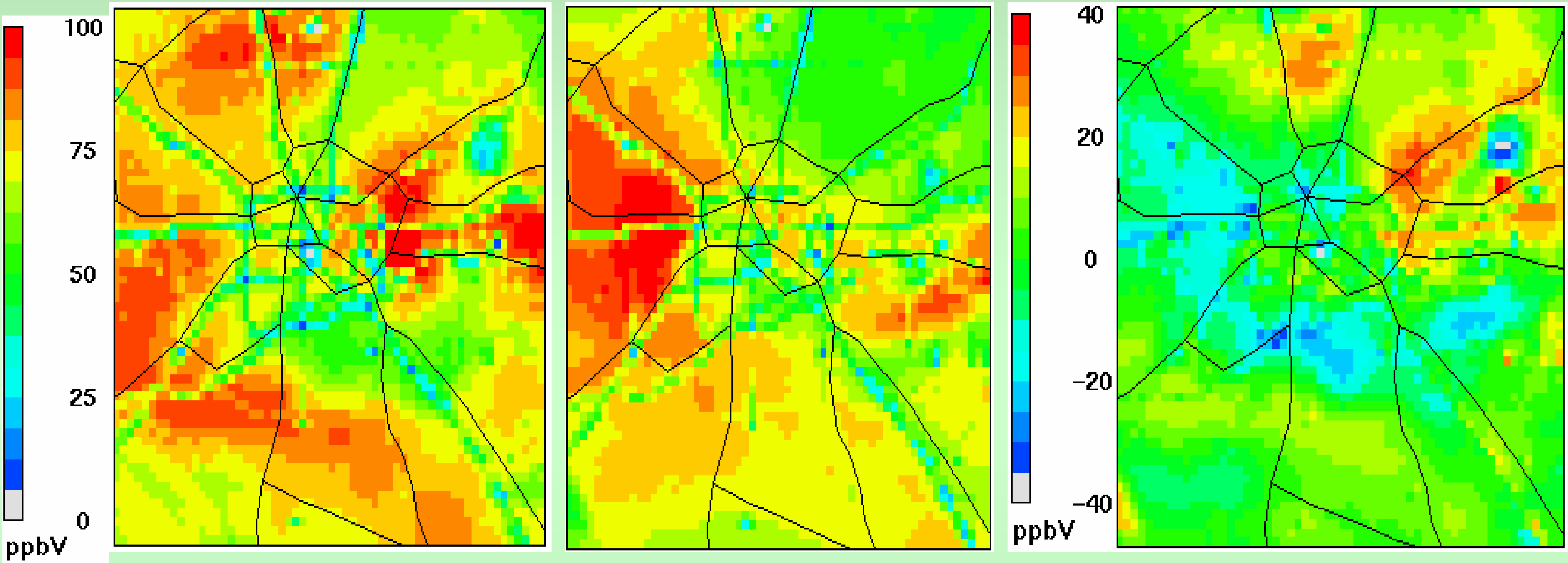
A: Simulated base-case ozone [O3], ppm, for central California, July 31, 2000 (1300 PDT) at 4km resolution.

B: 1km-resolution detail of simulated base-case ozone [O3] at 1300 PDT, July 31, 2000 within the uMM5 grid for the Sacramento area. The approximate location of the area with high-rise buildings is shown with black ellipse.

C: Changes in ozone concentrations (ppm) as a result of heat island control via increased urban albedo in the Sacramento area.

4. CMAQ (1 km grid model ozone in Houston, 2100 GMT)

UCP | **noUCP** | **Difference (UCP-noUCP)**



- Significant differences in the spatial patterns shown between UCP and noUCP runs (titration effect occurs in both sets)
- Flow, thermodynamics & turbulent fields differ between the UCP and noUCP simulations & contribute to differences

5. Overall Summary NUDAPT provides:

- **Platform** for advancing state of urban modeling- accommodates new modeling systems, new (sets of) parameterizations
- **Capabilities for Urban applications** in UHI modeling guidance
- **Community framework** facilitates collaborations
- **Urban** model focused system
- **Several tools** including regridding and remapping to different size & map projections
- **Prototypes** provide strategic means for extensibility of its capability to all cities (copycat principle)
- **Is non-stagnant** (cities grow), can accommodate finer resolution data, data refresh cycle.
- **Facilitates** handover from model development to application deployment
- **Extensibility** on International bases, e.g., EU sponsored Megacity studies, prototypes

Suggestions, Options, Levels of Collaboration

- Studies to advance modeling methodologies
- Perform specialized targeted application studies
- Contributions of data to NUDAPT
- Create a Community decision support system for UHI mitigation analyses either
  - within NUDAPT or
  - based on advanced models and NUDAPT system

5. FINAL REMARKS

- Prototype development was highly successful, Development is ongoing, needs support
- Current hosting at CMAS; possible future hosting at NCAR
- Flexible and powerful system (data, processing tools, accessibility, advanced State of Science meteorology, dispersion, and air quality modeling
- Can address and provide guidance on UHI mitigation on science bases
- **UHI Community can take advantage of, contribute to and enhance NUDAPT – Be a collaborator this current FY???**

NUDAPT Collaborators

- Michael Brown, Los Alamos National Laboratory
- Steven Burian, University of Utah
- Fei Chen, UCAR
- Ronald Cionco, U.S. Army
- Richard Ellefson, Private
- Mark Estes, Texas Center for Environmental Quality
- Johannes Feddema, University of Kansas
- Joe Fernando, Arizona State University
- Adel Hanna, UNC Institute for the Environment
- Teddy Holt, NRL
- Torrin Hultgren, CSC
- Maudood Khan, Georgia Department of Natural Resources
- Chris Kiley, Northrop Grumman; Defense Threat Reduction Agency
- Jocelyn Mailhot, Environment Canada
- Kungsun Park Arizona State University
- Lela Prashad, Arizona State University
- David Sailor, Portland State University
- Haider Taha Altostratus Inc.
- David Williams U.S. EPA

Thank you
for your time and interest

QUESTIONS?

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