Paper: Harmo11-124
Cambridge UK
July 2-5, 2007

Advancing Urban Dispersion and Air Quality Models using a Community-Based High Resolution Building and Urban Data Base System (NUDAPT)

"National Urban Database and Access Portal Tools"

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NUDAPT: a collaborative project

• Michael Brown	LANL	**Population data**
• Steven Burian	U of Utah	**UCPs/LULC**
• Fei Chen	NCAR	**WRF**
• Ronald Cionco	U.S. Army	Urban scale modeling
• Mark Estes	TCEQ	Houston Prototype
• Johannes Feddema	U of Kansas	Global – urban modeling
• Joe Fernando	Az State University	Phoenix prototype
• Adel Hanna	U of North Carolina	**NUDAPT Processors**
• Torrin Hultgren	CSC	**Portal developer**
• Maudood Khan	Georgia DNR	Atlanta Prototype
• Chris Kiley	DTRA	**133 City database**
• KyungSun Park	Az State University	Phoenix prototype
• David Sailor	Portland State University	**Anthropogenic heat**
• Haider Taha	Altostratus Inc.	**Advanced UCP in MM5**
• Aijun Xiu	U of North Carollina	Advanced UCP in MM5
• Richard Ellefsen	Independent	Army scale modeling
• Lela Prashad	Az State University	100 Cites Project
• JocelynMailhot	Environment Canada	Canadian Urban modeling
• Teddy Holt	NRL	Urban-coastal modeling

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Infrastructure for urban applications of air quality and dispersion modeling

- **Air Quality –Health**
  - Exposure assessments
  - Policy and Control strategies
  - Acute to chronic time scales
- **Homeland security**
  - Transport on episodic bases
- **Urban impact on climate change**
  - Thermal comfort, UHI mitigation
  - Impact of urban growth and structures on urban climate

- ***All above applications require accurate, but appropriate meteorology data to perform well!!***

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Presentation addresses choices and means to provide transport and flow fields specific to wide range of urban focussed dispersion and air quality modeling applications

- **Given**
  - **Boundary layers in urban areas are characterized by relatively large inhomogeneities** in its underlying surfaces.Roughness and z/L scaling may not apply when the assumption of surface homogeneity break down (e.g., as grid sizes decrease). Such situations occur in canopy flows, prevalent in urban areas.
  - **Advanced descriptions of flows applicable over such canopies are emerging;** they require differing degrees of aggregation of detailed information about the canopy including information about buildings, vegetation, coverage of impervious surfaces, etc. These descriptions are classified as urban canopy parameters, they tend to be highly dependent on grid size and underlying urban features. More than one set of descriptions may apply.
  - **High resolution data on building and urban structures is obtainable** that can be used to derive appropriate and simple to complex descriptive parameters.

- **NUDAPT's Community System Approach:**
  - **To be a modeler's system of tools** that makes possible to capturing and producing in parameterizations, a variety of descriptions of surface characteristics for use in meteorological models
  - **To facilitate dissemination of gridded sets** of data and parameterizations for varied urban applications
  - **To facilitate improvements to these sets of parameterizations** and to extending their spatial coverage
  - **To facilitate critical acute and chronic assessments of exposure** to harmful agents and air pollutants in urban areas.

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Harmo's Rules of Engagement

- Rule| 1: None of us is as smart as all of us

……..|P. Condit

Challenge: to prove Rule 1

- Ching's Corollary to Rule 1

Community system allows proof of Rule 1

e.g., CMAQ, MM5/WRF,

Dispersion "WIKI" AIR4EU

NUDAPT

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NUDAPT Design features

- **NUDAPT serves to facilitate the advancement of the following modeling paradigm:**
  - **That more than one set of urban descriptions (parameterizations) of processes that drive the meteorology over urban areas may apply.**
  - **That the sets of descriptors can range from simple to highly complex;**
  - **That the choice is dependent on the application.**

- **The NUDAPT implementation:**
  - **High resolution urban data is processed into gridded sets of parameters, for different grid sizes and for different modeling coordinate systems as needed.**
  - **High resolution data is either housed or by links, the daughter products are produced or modified as needed, ancillary data are obtained and gridded for air quality and dispersion applications.**
  - **Portal technology invoked to provide these data products.**

- **Portal technology facilitates NUDAPT's Community approach**
  - **Varied applications from operational forecasts for emergency response, health advisories to urban planning and air quality and exposure assessments**
  - **To support R&D investigations towards model improvements**
  - **To improved mitigation strategies**
  - **Towards understanding changing climatology**

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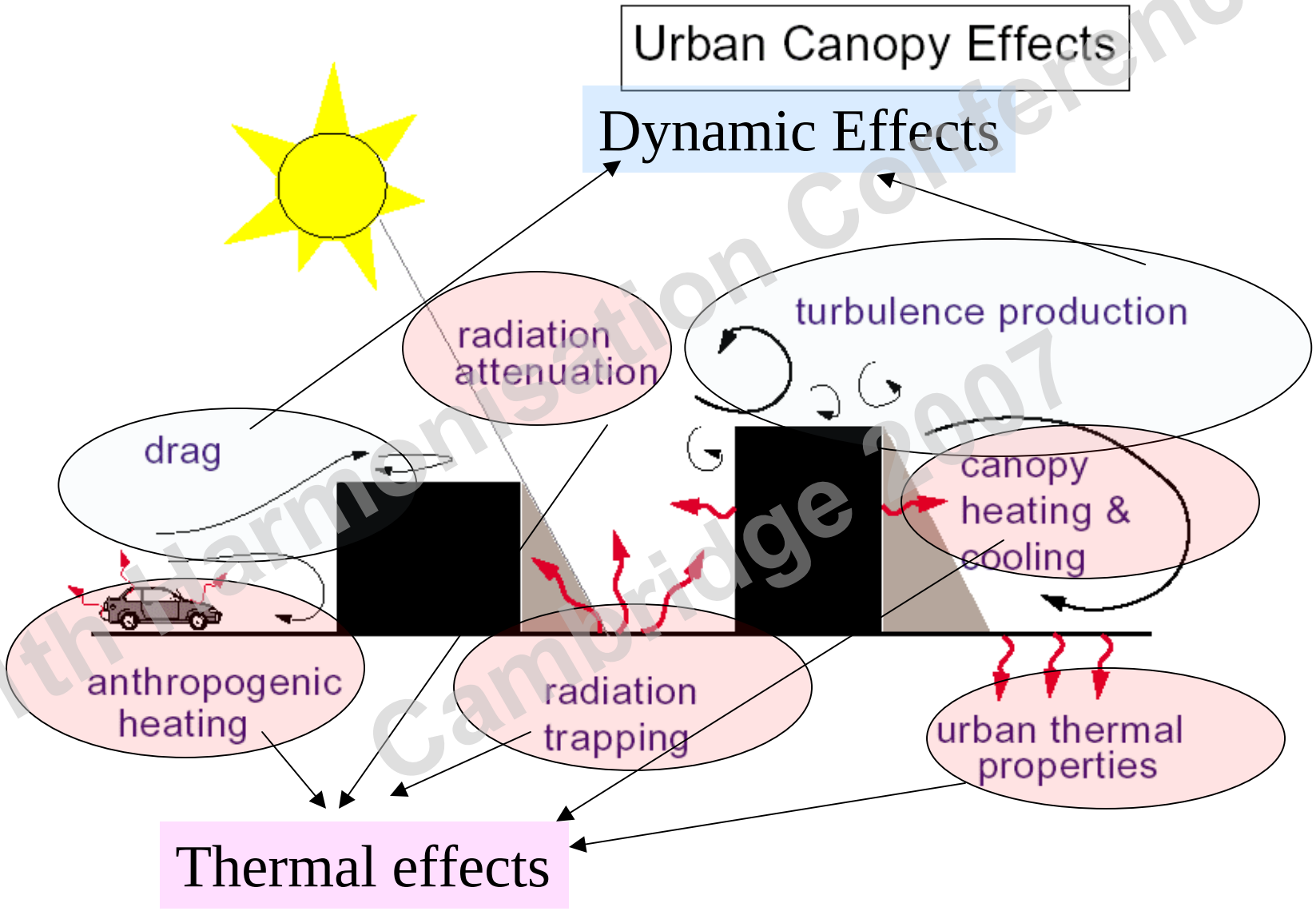

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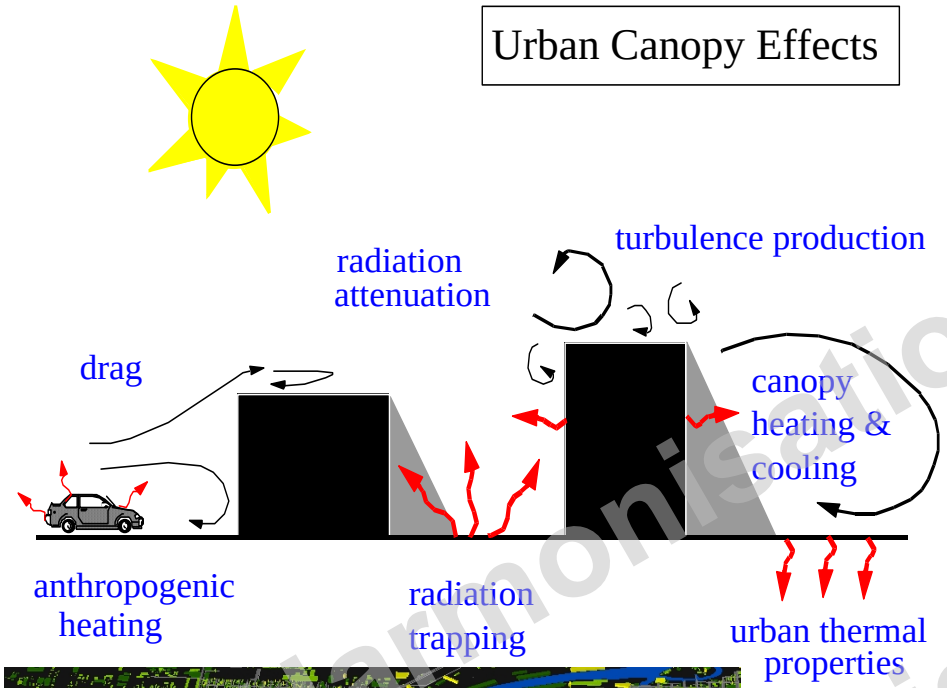
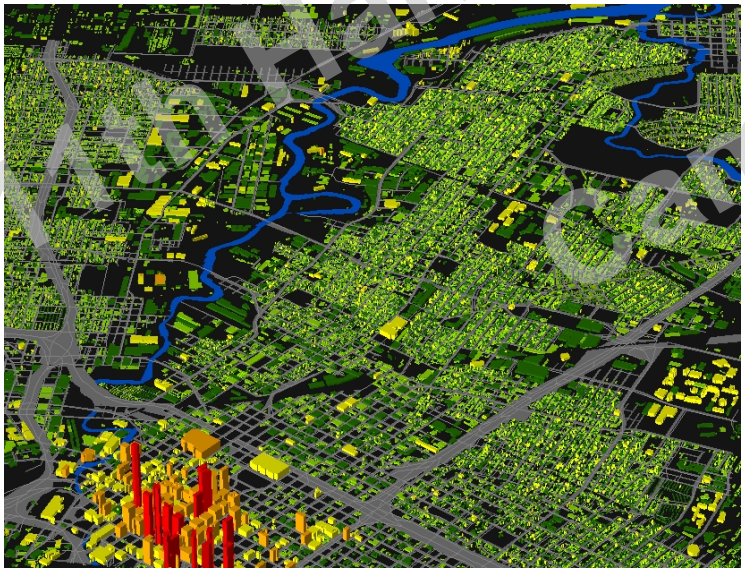
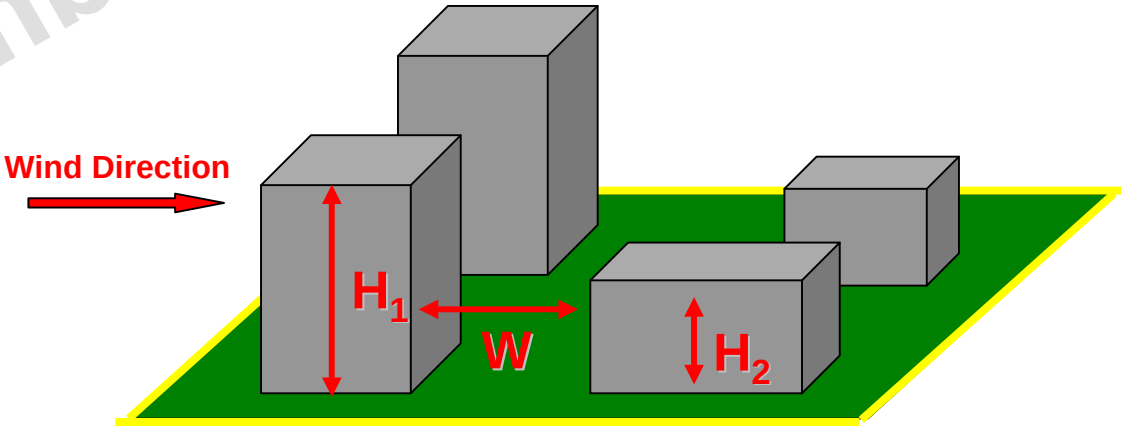
METHODOLOGY: Meso-urban scale modeling



Modeler's needs:
To capture the area-average effect of the urban area in mesoscale atmospheric models

Solution:
Modelers have implemented urban canopy parameterizations into their models (e.g., MM5, WRF, HOTMAC, COAMPS…) based on building geometry data





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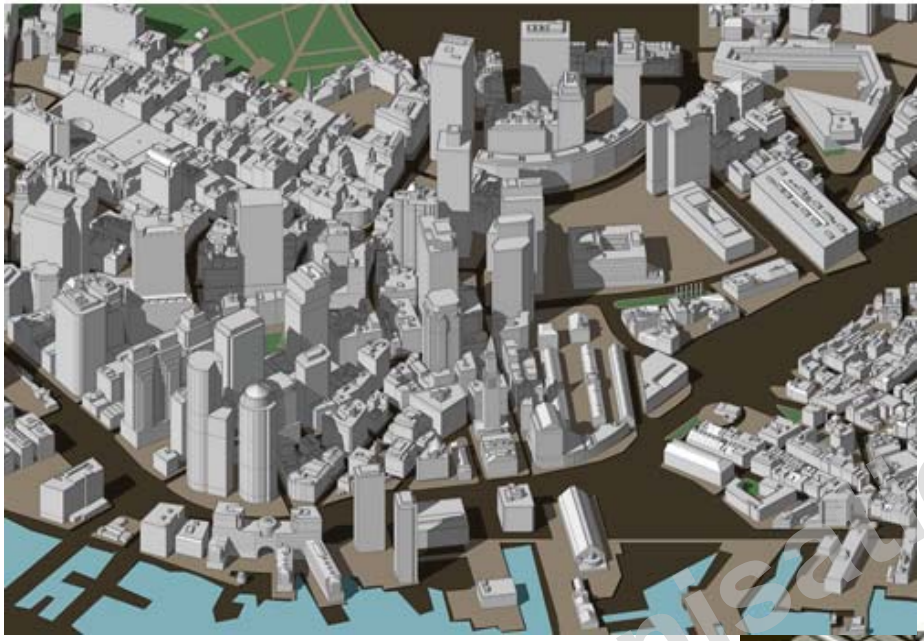
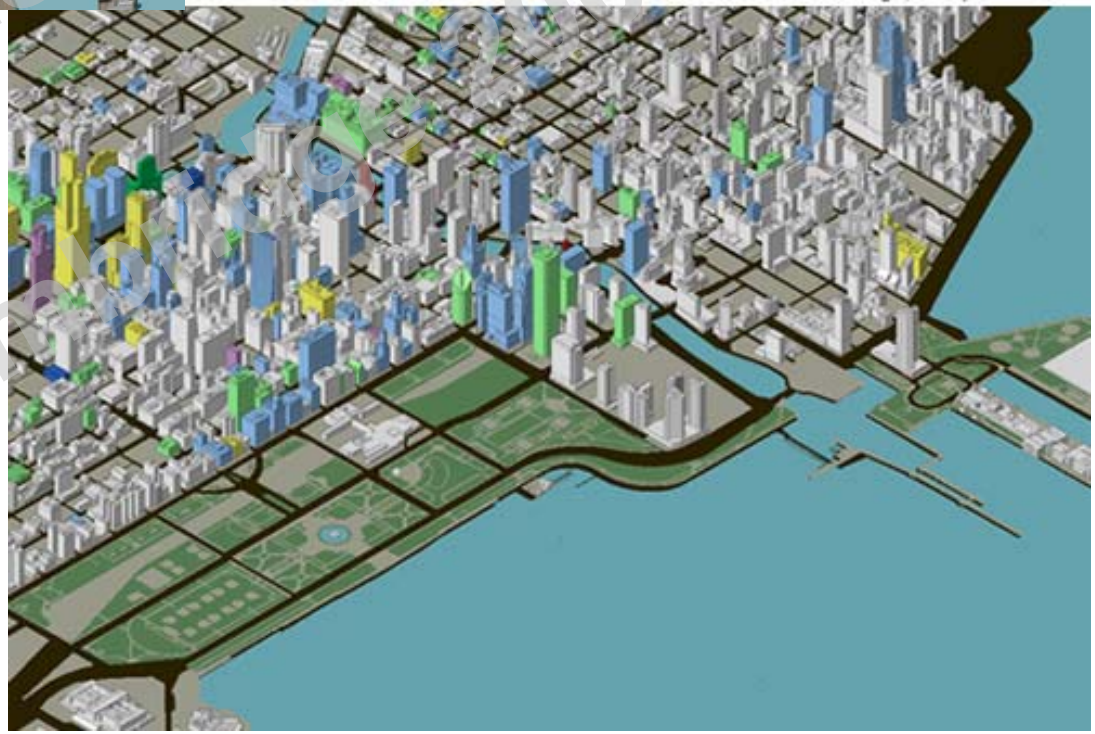


We have technology and means for obtaining building data at high resolution; such data and ancillary data are becoming increasingly more available for our major cities (133 in USA)



High resolution urban morphological data from lidar mapping and photogrammetric techniques. Also other remote sensing data, MODIS, ASTER and SAR technology.

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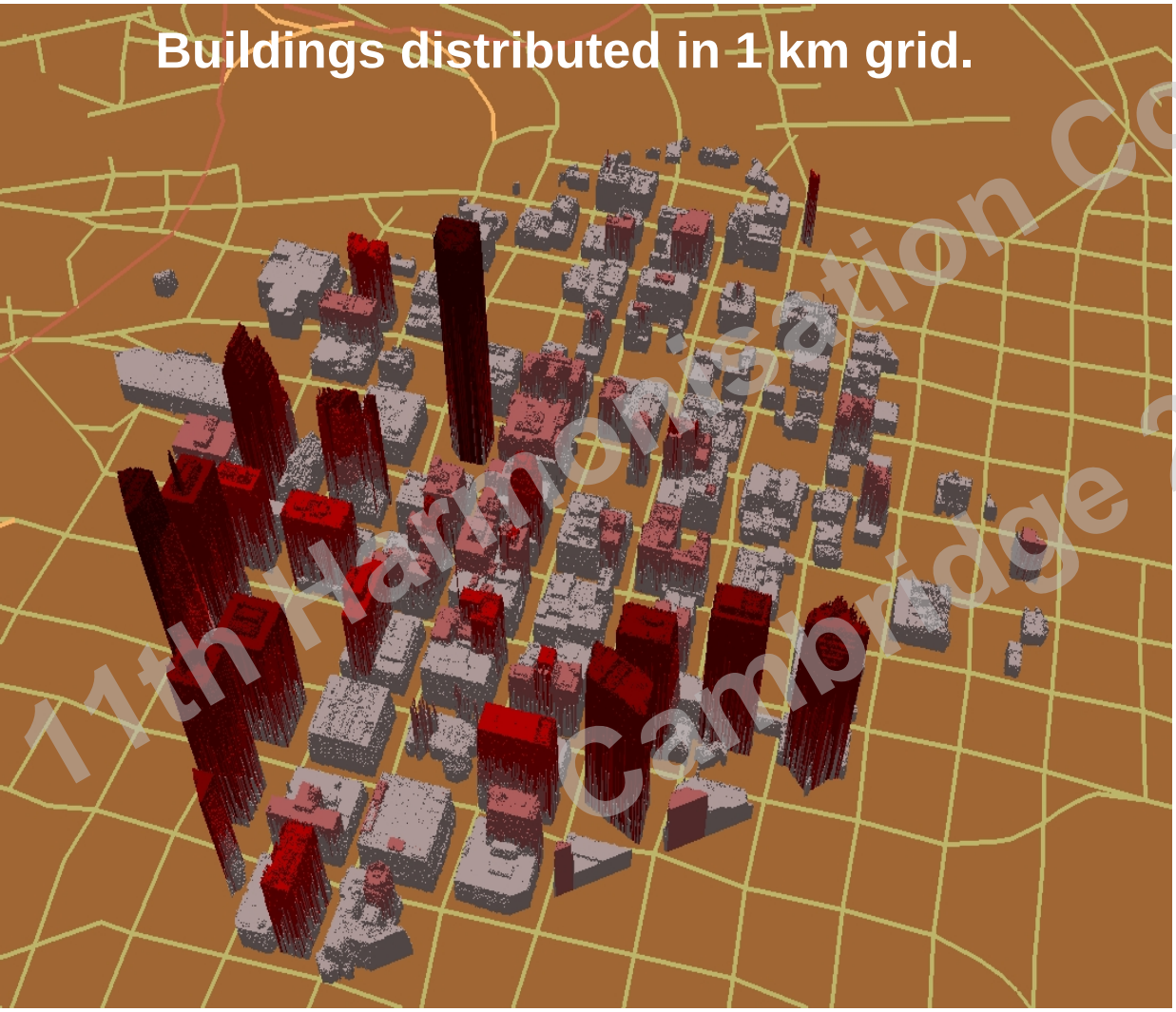
Example of building data from lidar mapping



Meso-to-urban scale: Model produces single meteorology profile applicable to grid cell. Results influenced by aggregating the effects of buildings .

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

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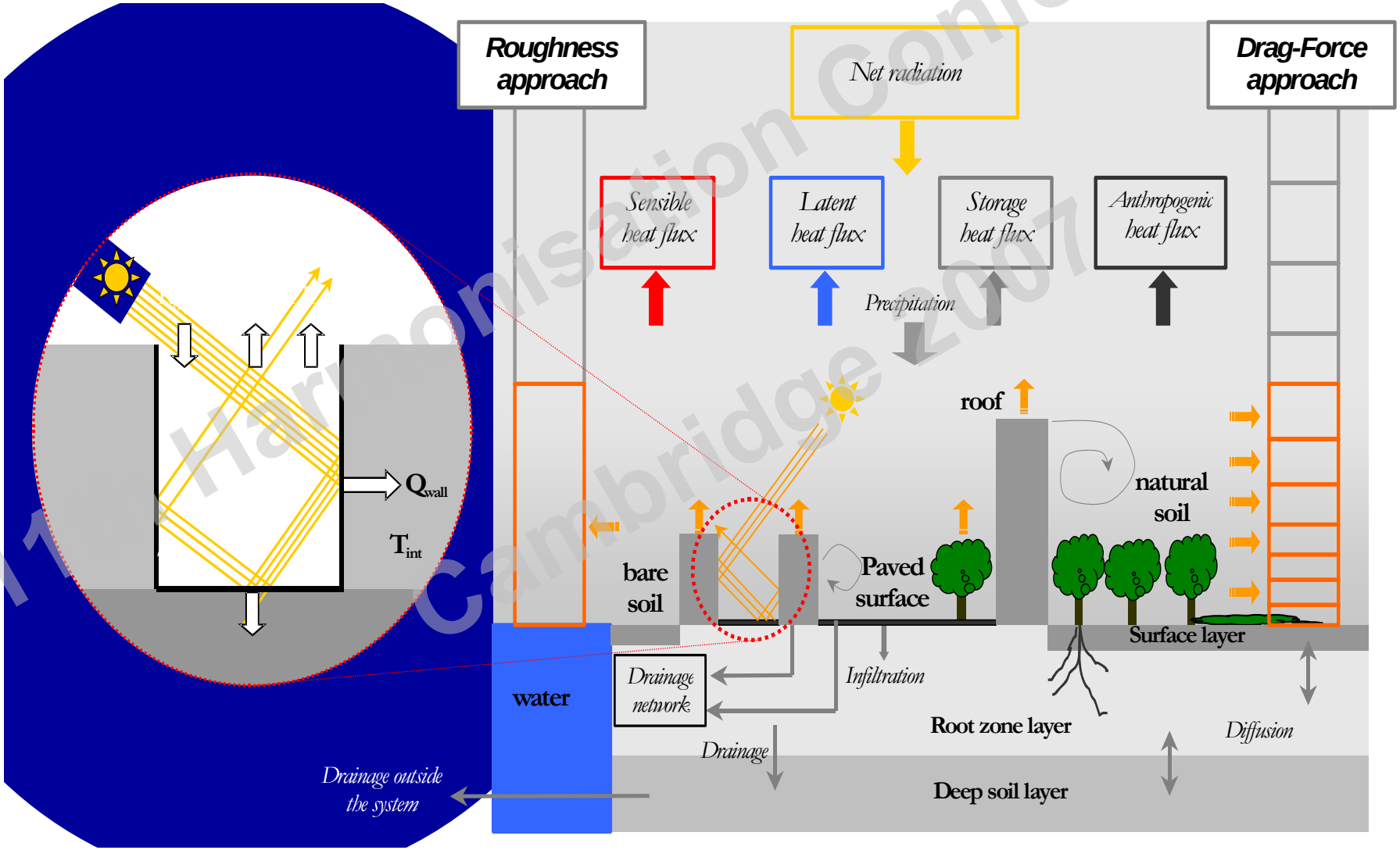
An implementation:
DA-SM2U in MM5 (Gayno-Seamon sub-system)

- o Urbanization introduced at grid sizes of ~1km using drag approach (DA)
- o Land surface model (SM2-U)
- o Additional, within canopy layers



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Gridded (1 km) Urban Canopy Parameters (UCP) from high resolution data for urbanized MM5

CANOPY UCPs	BUILDING UCPs	VEGETATION, OTHER UCPs
		Mean vegetation height
Mean canopy height	Mean Height	**Vegetation plan area density**
Canopy plan area density	Std Dev of heights	**Vegetation top area density**
Canopy top area density	Height histogram	**Vegetation frontal area density**
Canopy frontal area density	Wall-to Plan area ratio	
Roughness Length*	Height to width ratio	**Mean Orientation of Streets**
Displacement height*	**Plan area density**	Plan area fraction surface covers
Sky View Factor	**Rooftop area density**	**% connected impervious areas**
	Frontal area density	Building material fraction

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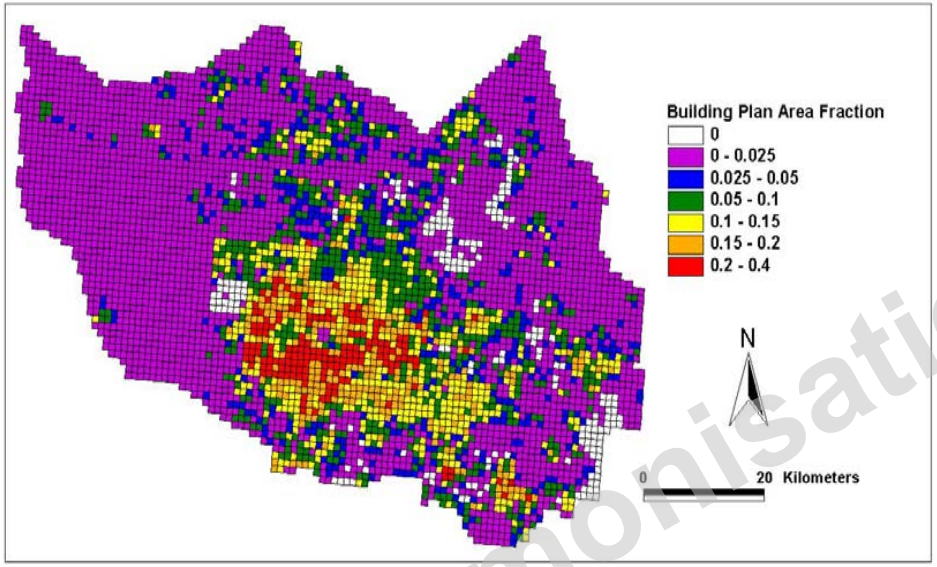
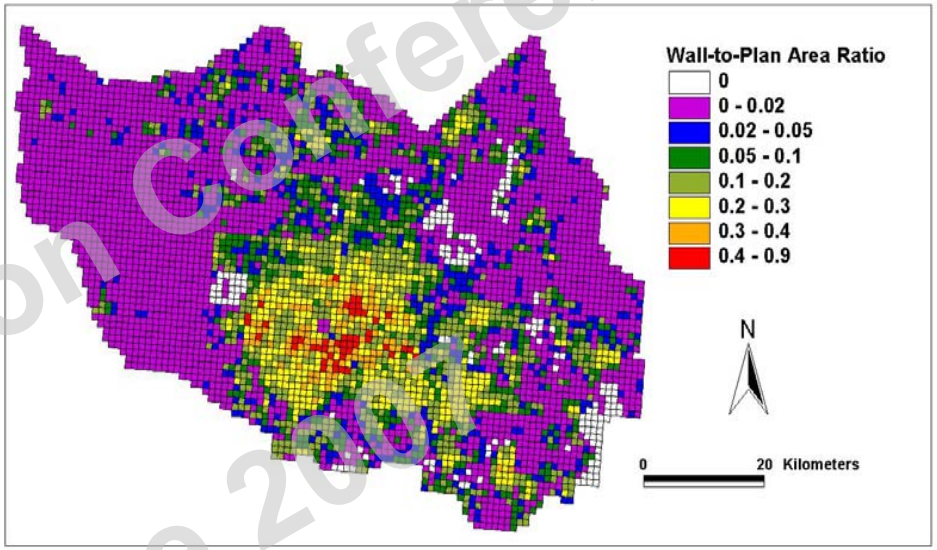
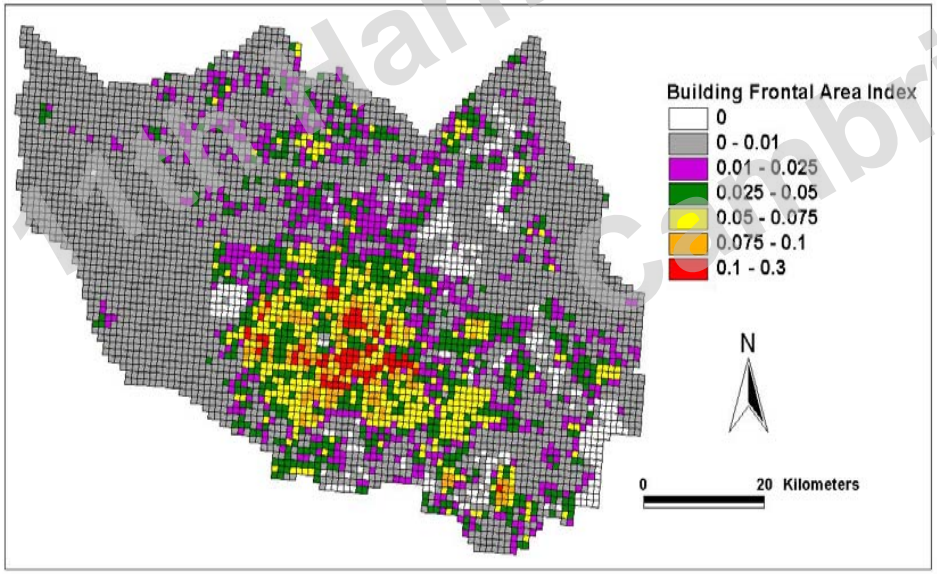
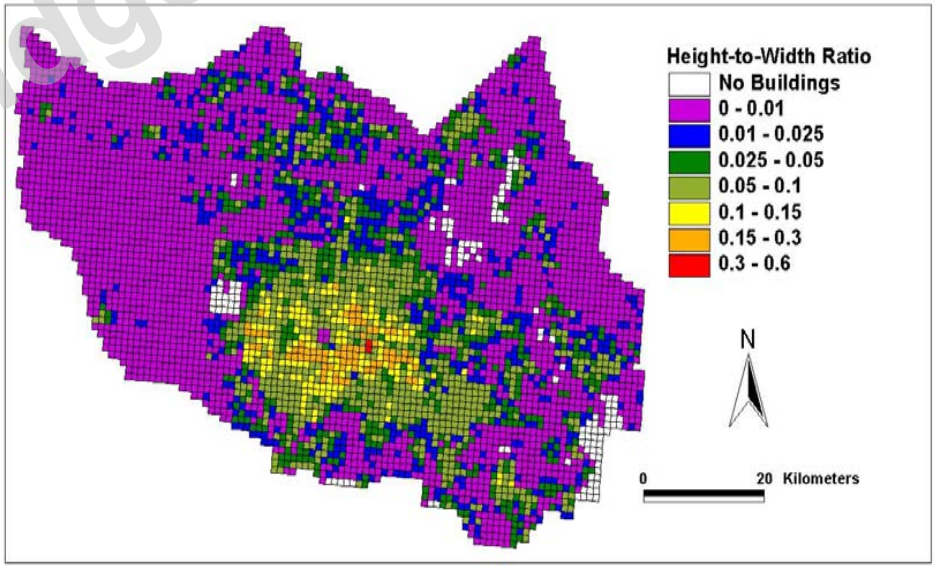
•Parameters used in RA formulations **Height dependent UCP**

Selected Urban Canopy Parameters per 1 km^2 cells for Harris County
NOTE! Each grid cell has unique combination of UCPs









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Prototypic Implementation
The "NUDAPT" Framework

- **Urban modeling is its major focus**
- **Adopts a community system paradigm-**
  - Encourages collaborations, accelerates model advancements with Portal technology
  - Supports various meteorological modeling systems, others are possible
  - Broad user base (Model developers to users)
  - Extensible (to smaller scales, to current and future city structures, to revised sets of UCPs)
- **Database consists of primary and derived parameters**
  - High resolution geospatial data: repository or links (133 cities in USA)
  - Appropriate and complete set of parameterizations at urban grid scale
  - Ancillary data (to facilitate applications)
  - Allowance for evaluation, operational utility
- **Features include basic processing methodologies and tools**
- **Selected cities serves as example prototypes to highlight capabilities and features**

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Example Sensitivity Studies

- I. Meteorological dispersion parameters
- II. Air quality simulations
- III. Dispersion of agents

- Above examples based on model results for Houston Texas, August 2000
- Compare outputs of standard vs urbanized version of MM5 at 1 km grid size
- Urbanized version used UCP drag formulations and soil-BL (SM2-U) model

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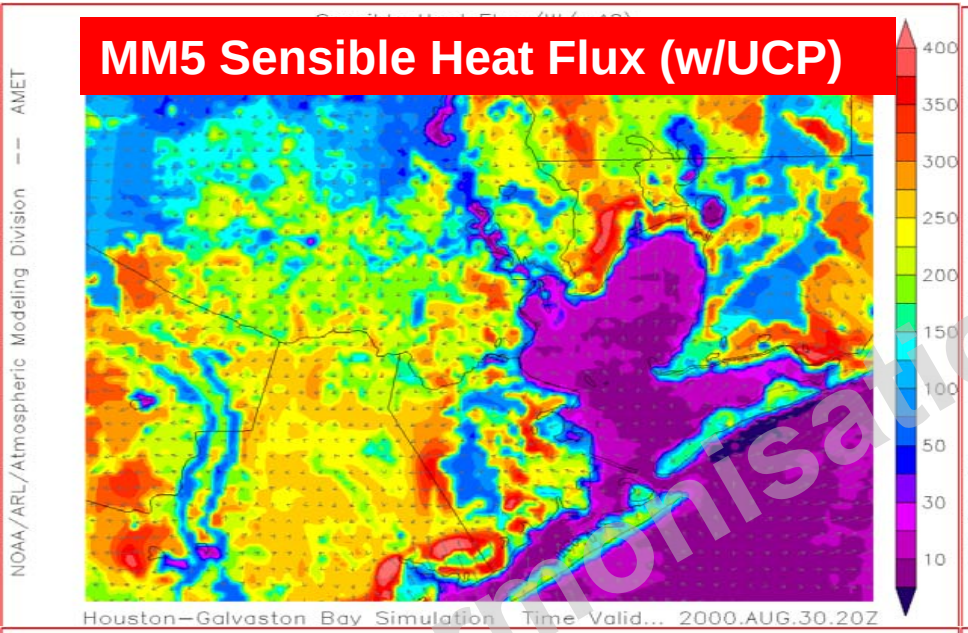
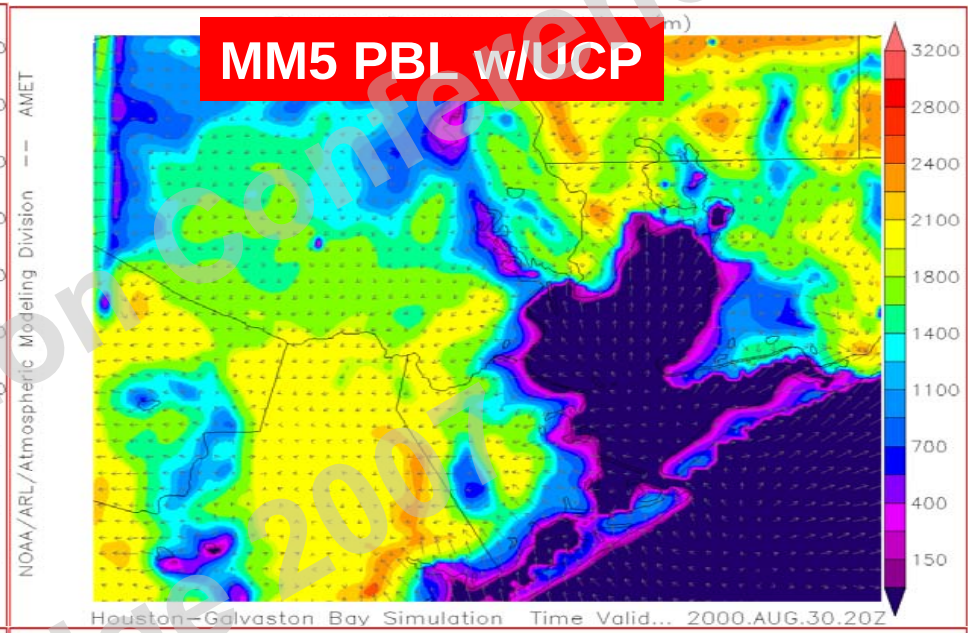
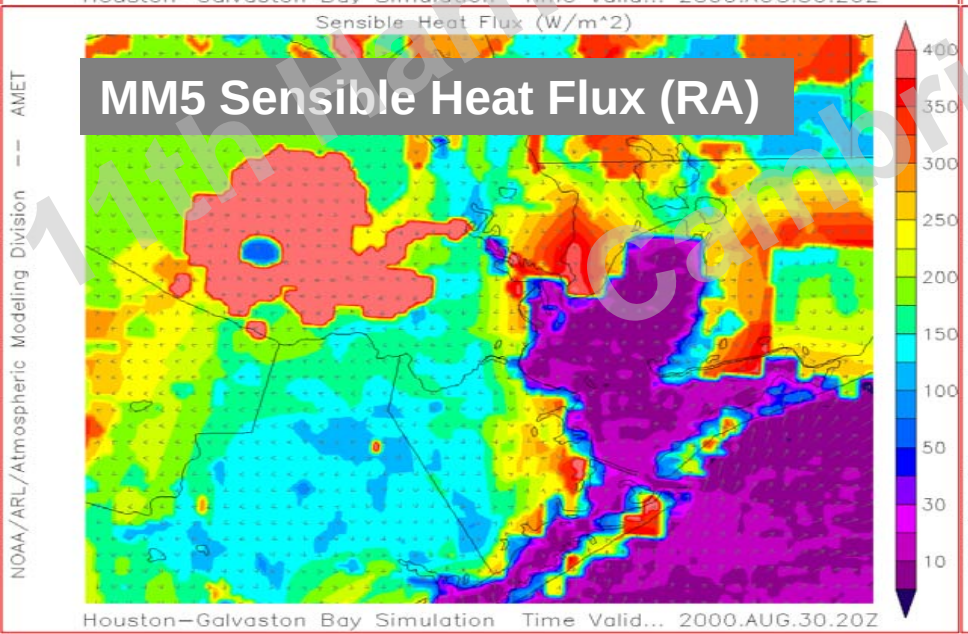
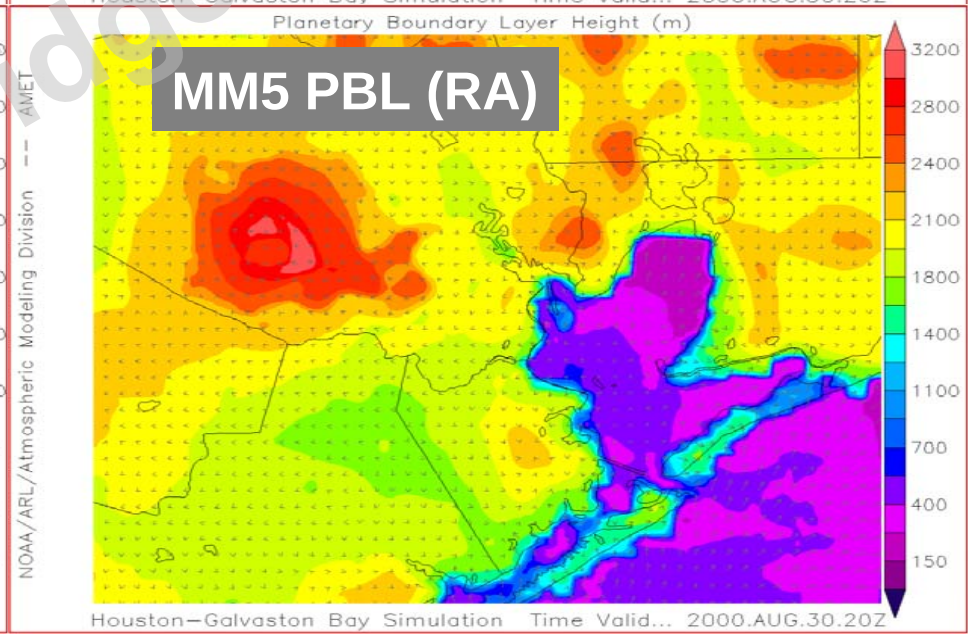
I. Sensitivity study: Comparison of results using

DA-SM2U (UCP version) Standard MM5 (RA)









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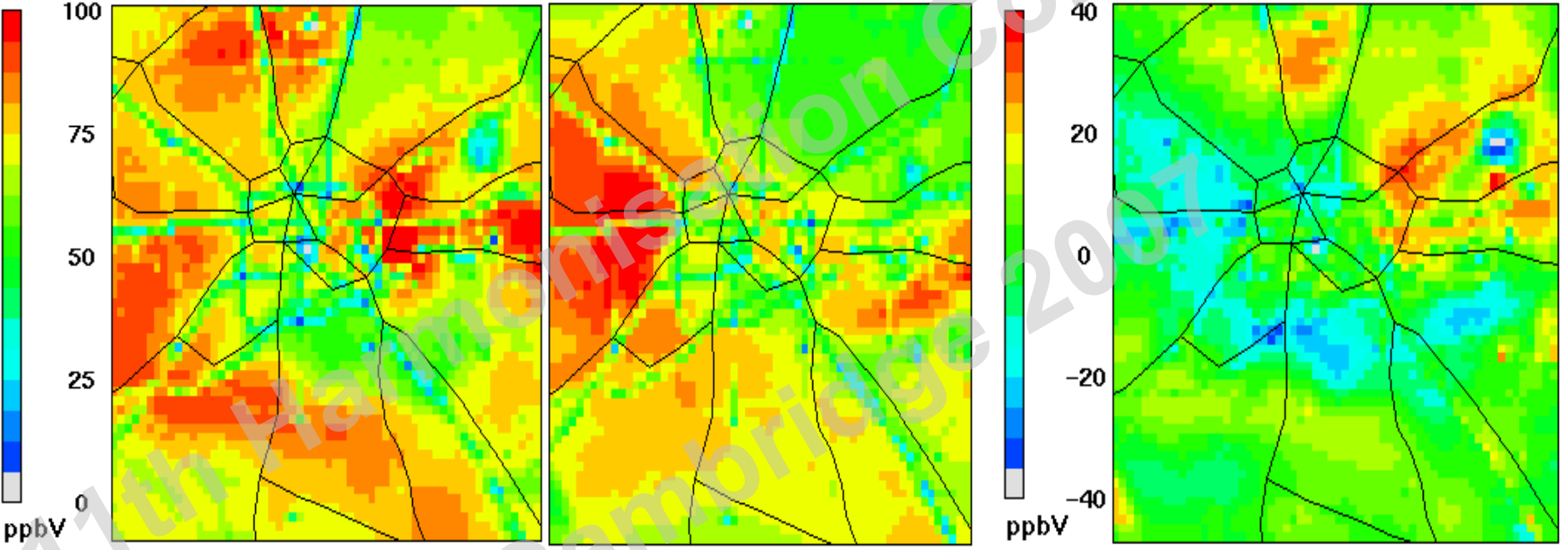
II. Ozone results of 1 km gridded CMAQ simulations 2100 GMT, August 30, 2000

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



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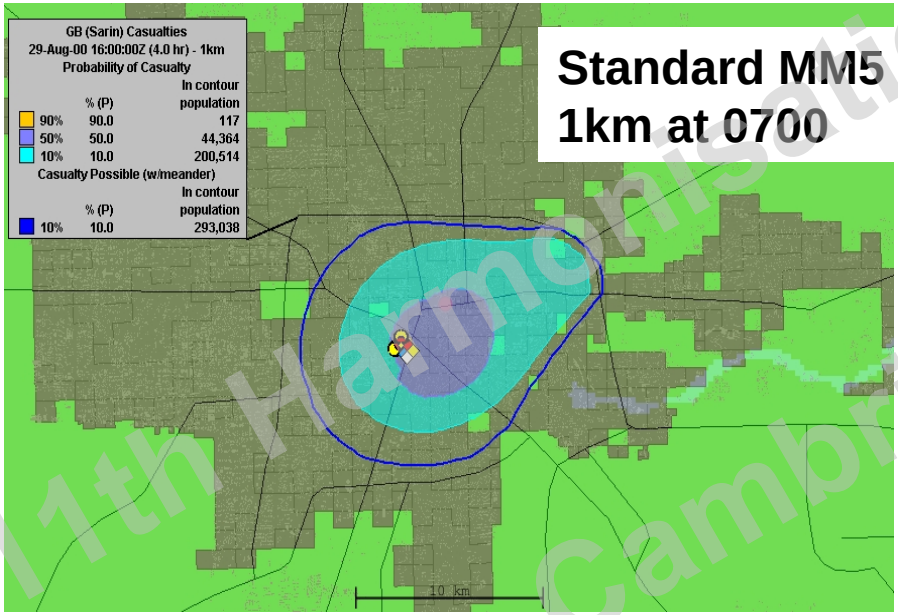
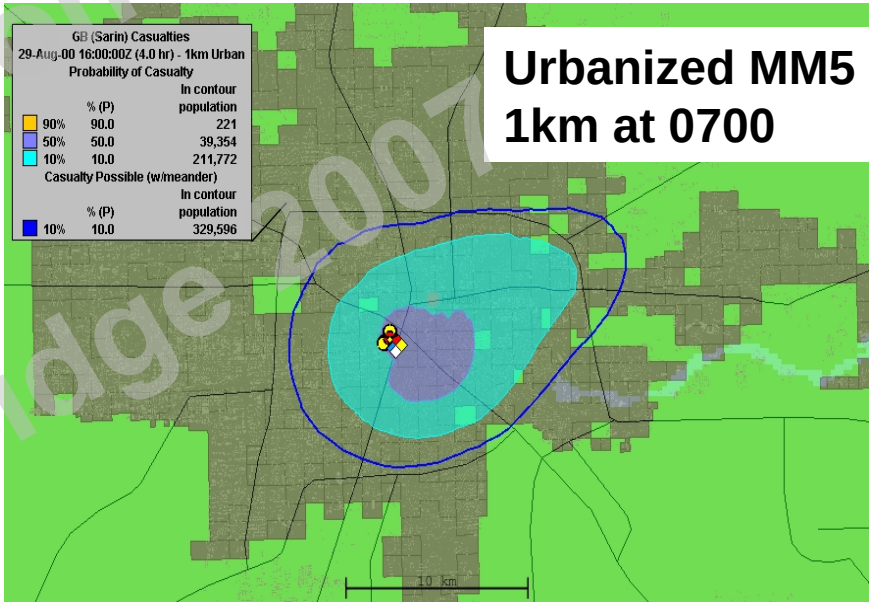
- **Significant differences in the spatial patterns seen between UCP and noUCP runs (titration effect occurs in both sets)**
- **Flow, thermodynamics & turbulent fields differ between UCP and noUCP simulations & contributes to differences**

III. Dispersion Study using HPAC

The Hazard Prediction and Assessment Capabilities (HPAC) system is now driven by modeled meteorology (MM5 and soon by WRF):
We are beginning to perform sensitivity study to grid size and to urbanization with Reynolds Averaging vs detailed UCP versions.





At this time we have successfully linked urbanized MM5 with HPAC.
Limited results available at this time. Results shown are for 0700.
Results pending for different time of day release times
Urbanized MM5 comparative reduction in spread not pronounced at 0700

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NUDAPT Portal: Two systems, One Whole

- **Implementation of Ching's Corollary**
- **Quickplace**
  - Powerful, flexible collaboration suite
  - Built-in security controls, file sharing ability
  - Leverages existing EPA Lotus Domino technology
- **Data Processing and Download Portal**
  - Delivers server-side data processing, minimizing or eliminating the need for desktop GIS
    - Generalized methodology for deriving alternative sets of UCPs
    - GIS based tools or special processors called "Spatial Allocator" to perform generalized regridding and grid geo-referencing capability
  - Responsive data exploration map viewer
  - Relies on ESRI's ArcGIS Server technology

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Quickplace Welcome

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Quickplace Summary

- Collaboration tool – what the group gets out depends on what the group puts in
- Easy to share documents, model results, smaller datasets (less than 200MB), presentations, etc
- Available calendar/task management tools
- Help build consensus on UCP methods and strategies
- Tool lets you manage the collaboration

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Data Download Portal

- Map
  - AJAX for smooth dragging and zooming
  - Built-in identify, measure, and magnify tools
  - Dynamic table of contents
- Data repository
  - Quickly import data, add to map, publish to web
  - Tightly integrated with windows security
  - GIS tools allow fast, easy data pre-processing

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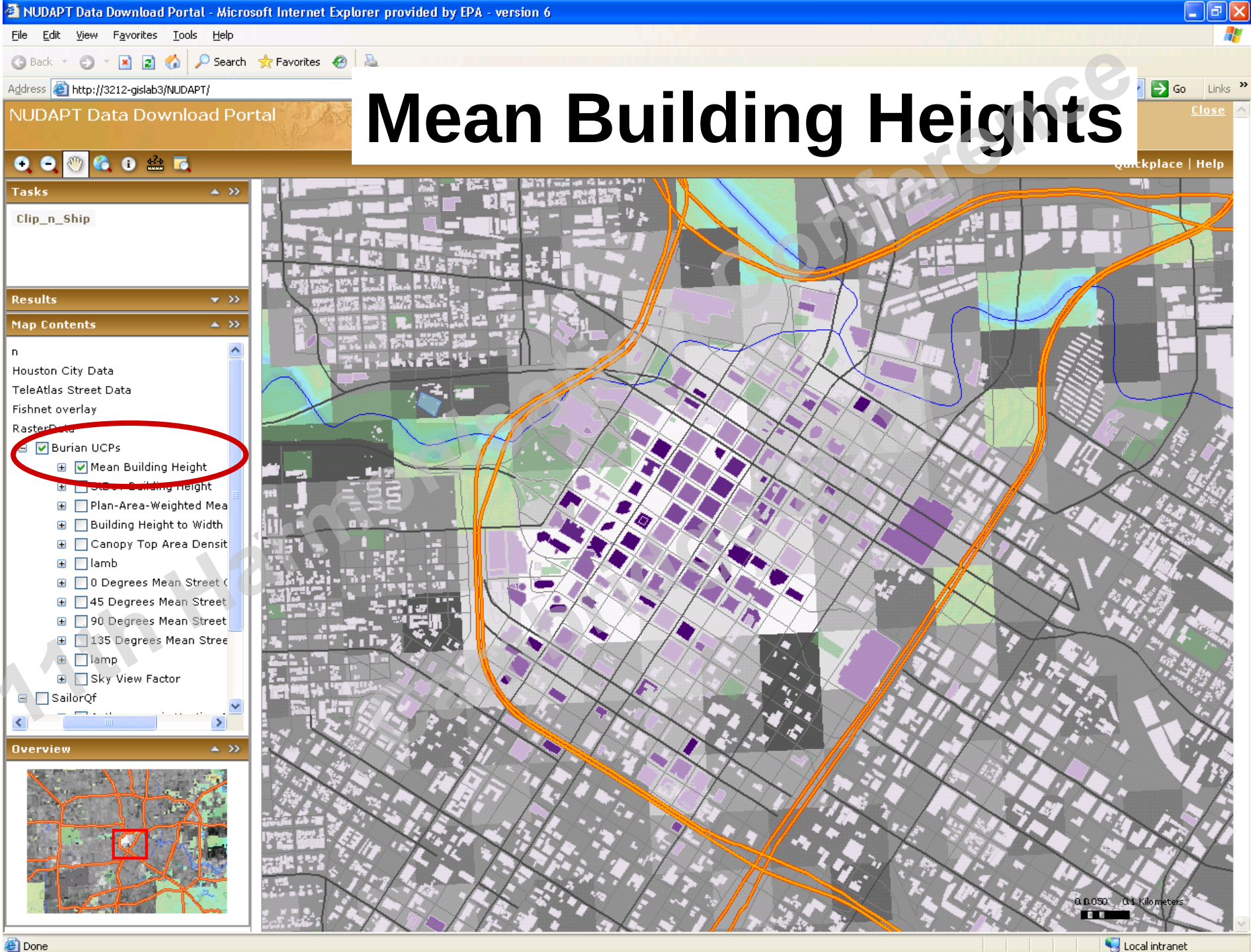
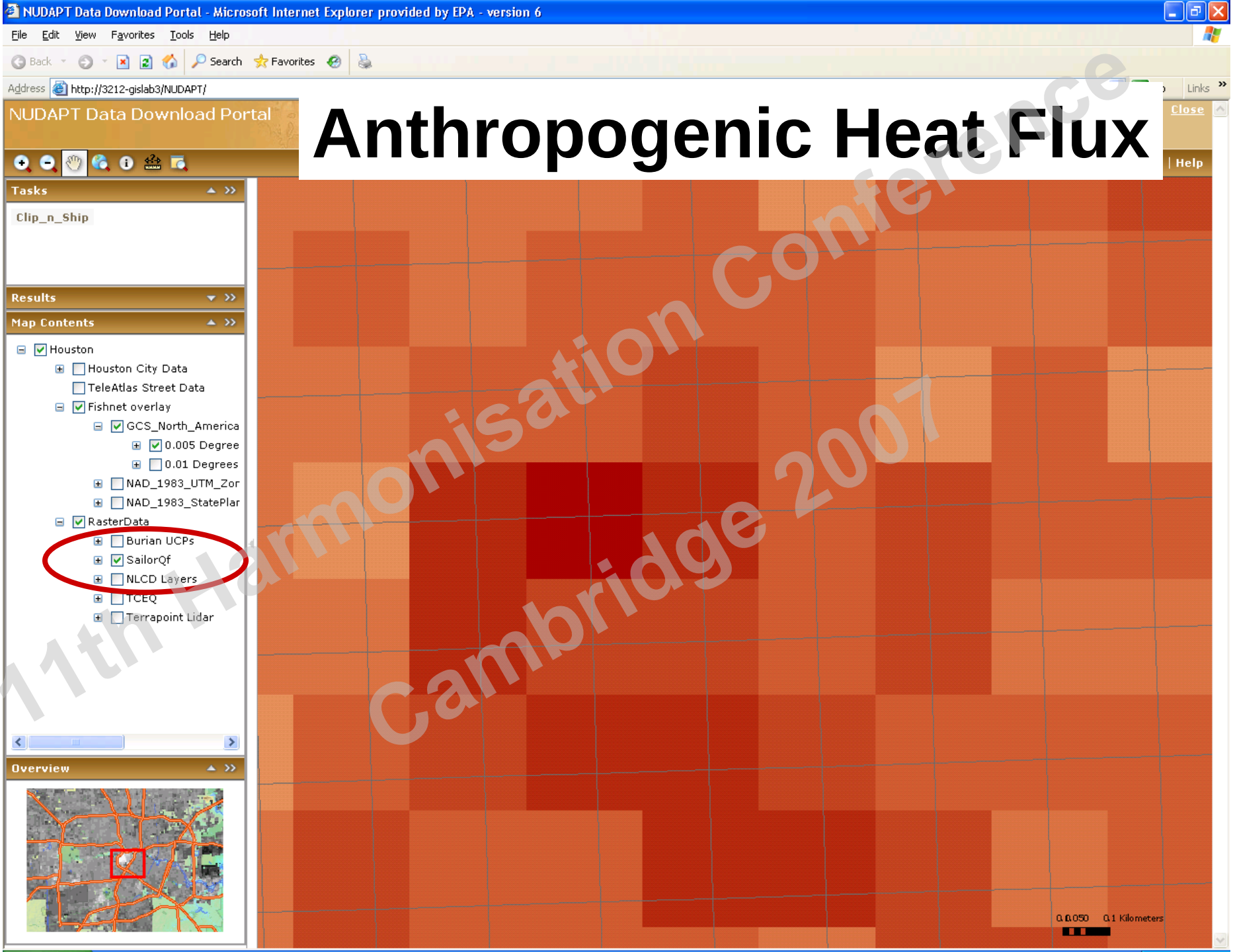


Mean Building Heights


NUDAPT Data Download Portal - Microsoft Internet Explorer provided by EPA - version 6
File Edit View Favorites Tools Help
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Help
Anthropogenic Heat Flux
Tasks
Clip_n_Ship
Results
Map Contents
Houston
Houston City Data
TeleAtlas Street Data
Fishnet overlay
GCS_North_America
0.005 Degree
0.01 Degrees
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NAD_1983_StatePlar
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Burian UCPs
SailorQf
NLCD Layers
TCEQ
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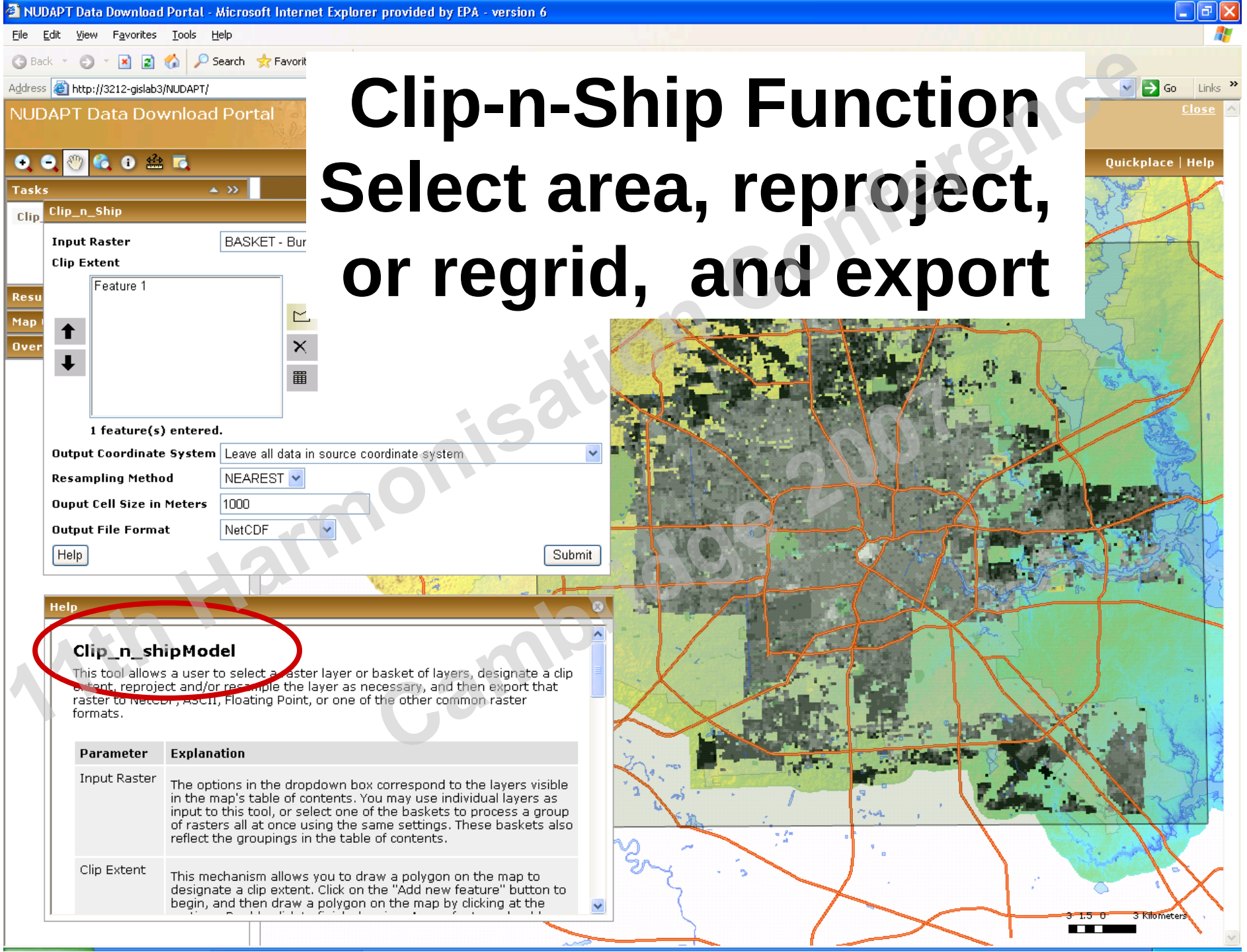
Clip-n-Ship Function
Select area, reproject, or regrid, and export



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Other model systems

- Canadian model based on TEB
- Global model with urban features
- COAMPS
- Urban-Micro scale (US Army)
- Advanced urbanized WRF with canopy-drag formulations
- International collaborations being explored

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UCPs for urbanized WRF(Current release)

- Urban fraction
- Building height, ZR
- Roughness for momentum above the urban canopy layer, Z0C
- Roughness for heat above the urban canopy layer Z0HC
- 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
- Emissive 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

- **Canopy parameters for improved drag formulation under development**

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SUMMARY: Urban database conceptual design provides

- **Platform for advancing state of urban modeling- accomodates new modeling systems, new (sets of) parameterizations**
- **Sets of daughter products supports different implementations for different applications**
- **Community framework facilitates collaborations**
- **Modeler's focused system**
- **Several tools including regrid and remap to different size & map projections**
- **Prototypes provide strategic means for extensibility of its capability (copycat principle)**
- **As non stagnant (cities grow), can accommodate finer resolution data, data refresh cycle.**
- **Facilitates handover from model development to application deployment**

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Added feature(s)
Anthropogenic heat flux in NUDAPT

- Anthropogenic heating (Q_f) can be a significant component in the urban energy balance, rivaling solar input in both summer and winter
  - **Nominal (mid-latitude) solar radiation profile: 0 to 500 W/m^2 in winter; 0 to 1000 W/m^2 in summer**
  - **Anthropogenic heating in larger cities averages 10 to 100 W/m^2 over the entire urban extent, but reaches 500 to 1000 W/m^2 within the urban core***
- Anthropogenic heating input in mesoscale models has been shown to impact significantly the urban climate
  - **Affects urban circulation patterns & mixing**
  - **Affects urban heat island magnitude, particularly at night and winter.**

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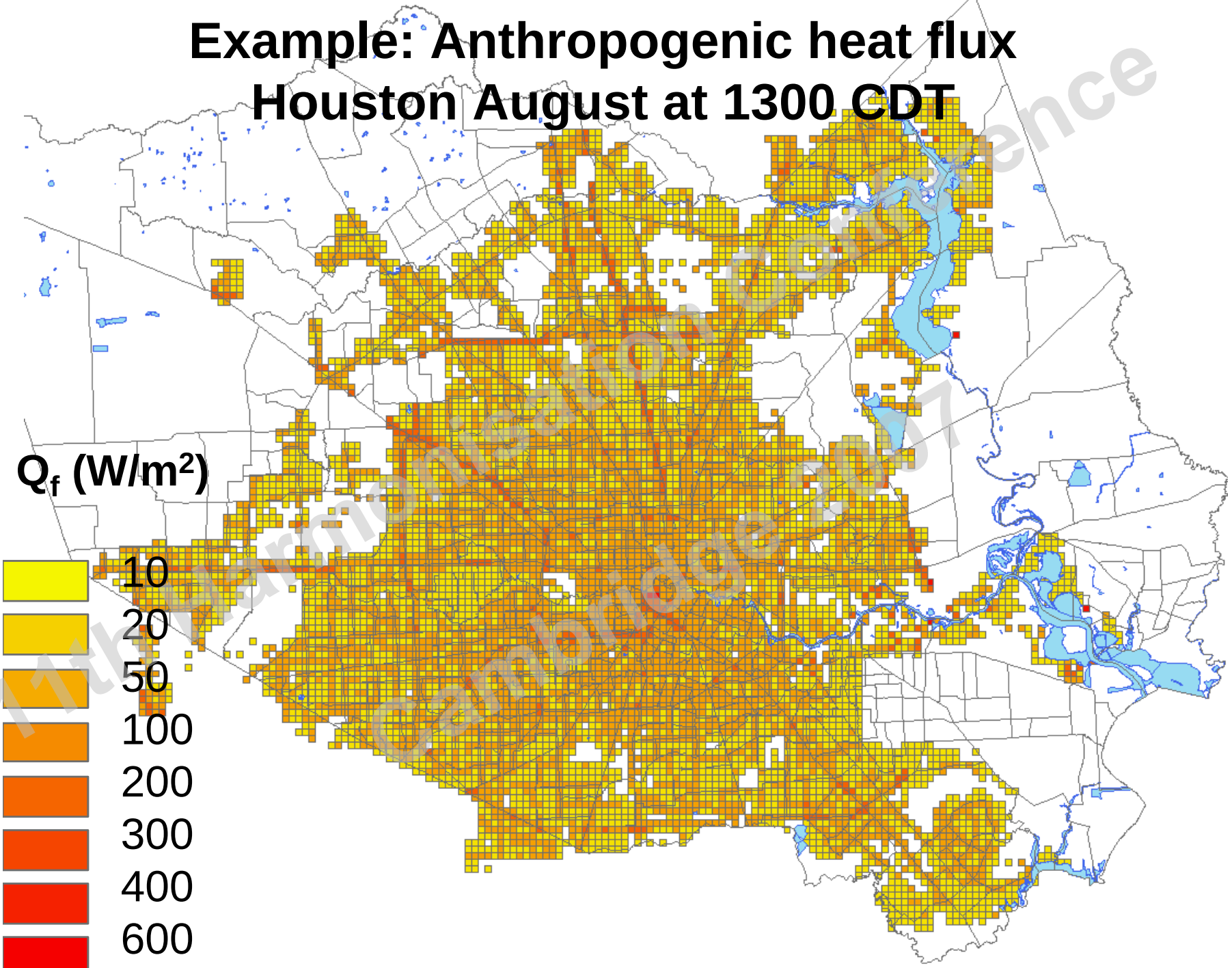
Example: Anthropogenic heat flux
Houston August at 1300 CDT



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Population data in NUDAPT

- Population information (and activity patterns) are important for conducting threat and health exposure assessments
- Basic data is from census, however, it represents nighttime population.
- Daytime population data has been processed and prepared by NUDAPT collaborator, Brown et al (LANL)
- Day and night population data needed for exposure studies

- NUDAPT can now provide day-night data at 250 m grids
  - USA Day-Night Population
    - - Daytime Residential
    - - Daytime Worker
    - - Nighttime Residential
  - USA Indoor-Outdoor Population
  - USA Sensitive Populations (<12, >65)
  - USA Population Mobility Matrix

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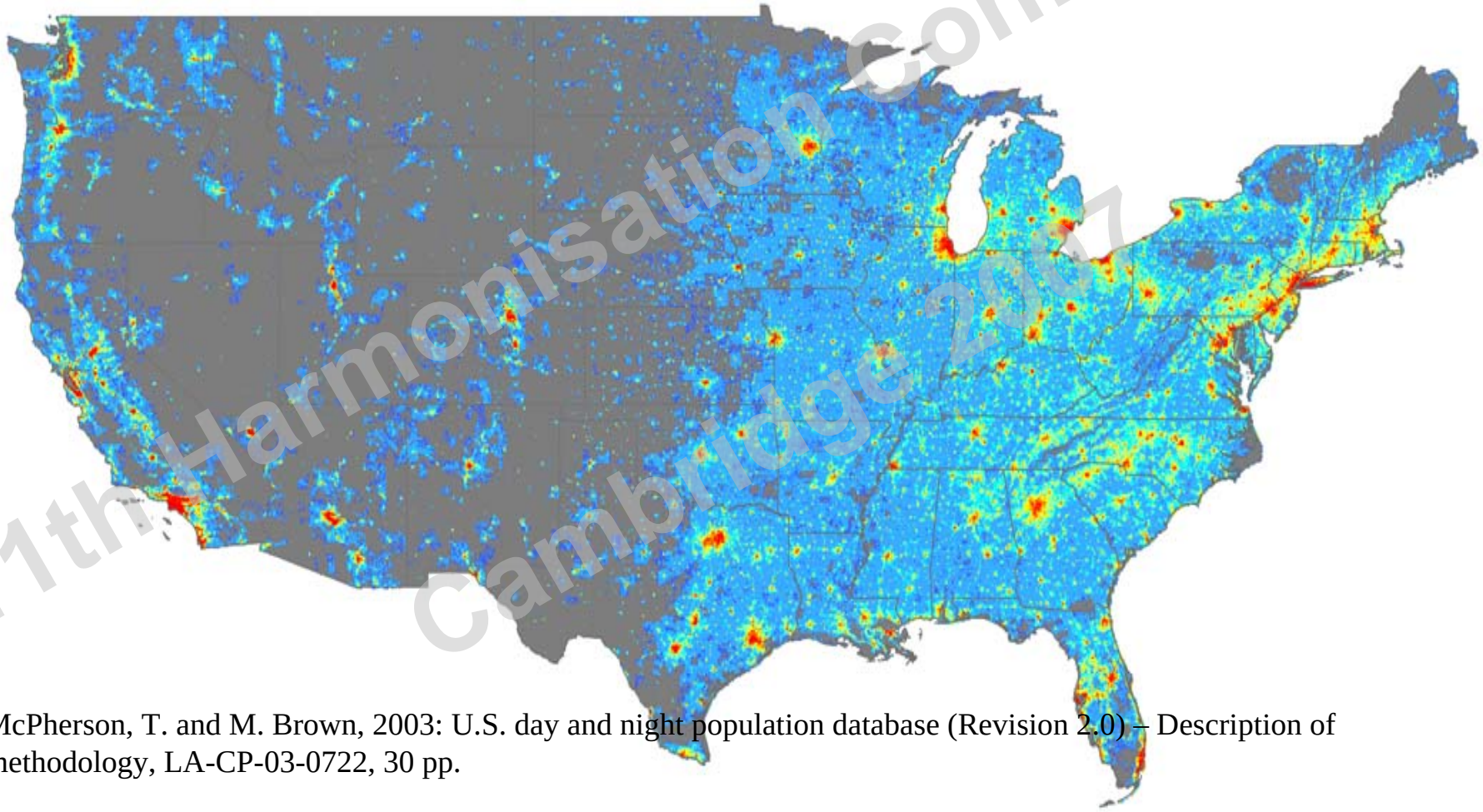
Day & Night Population database at 250 m resolution



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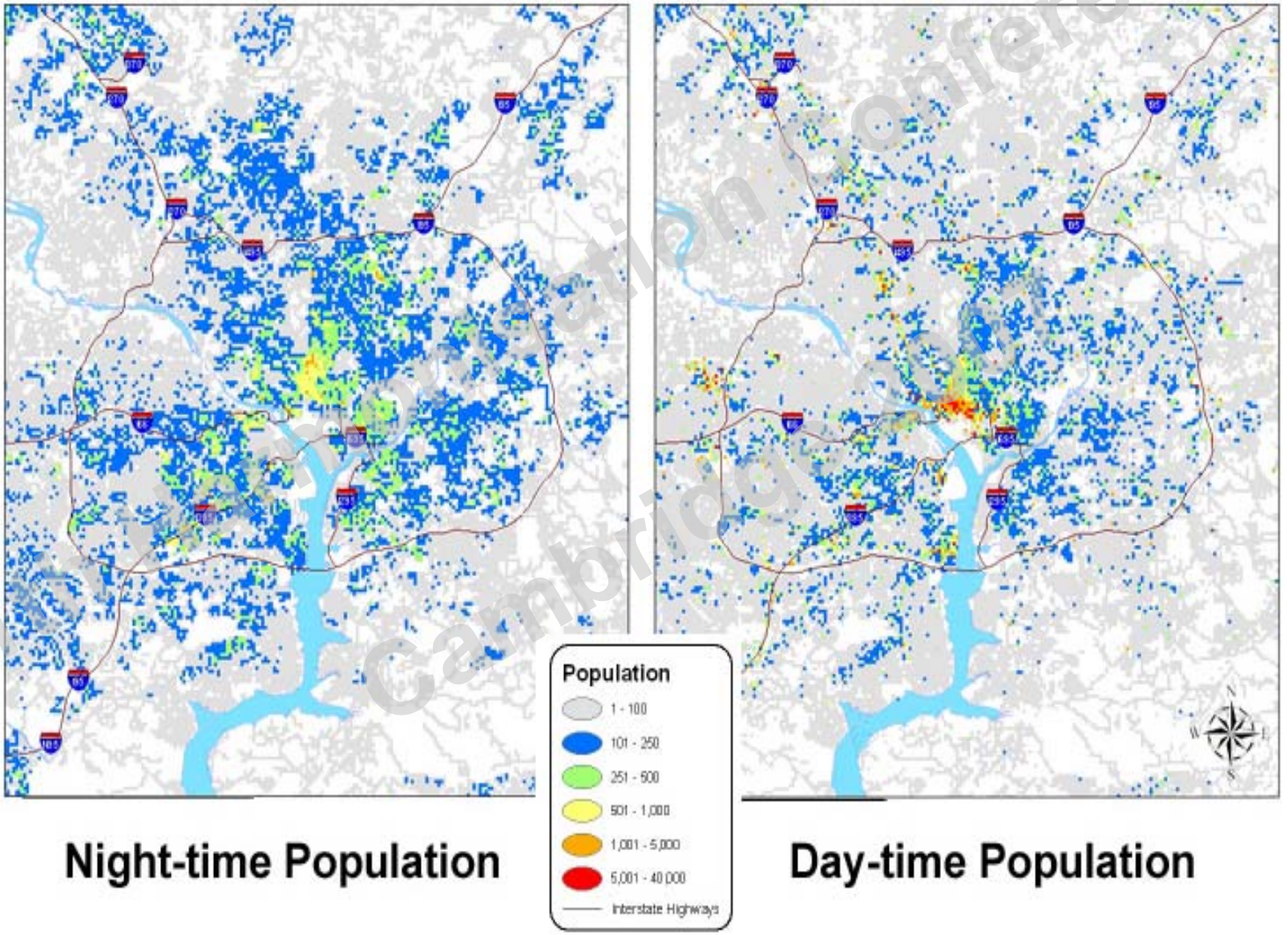
McPherson, T. and M. Brown, 2003: U.S. day and night population database (Revision 2.0) – Description of methodology, LA-CP-03-0722, 30 pp.

McPherson T., J. Rush, H. Khalsa, A. Ivey, and M. Brown, 2006: A day-night population exchange model for better exposure and consequence management assessments, 6th AMS Urb. Env. Symp., Atlanta, GA, LA-UR-05-, 6 pp.

Washington DC



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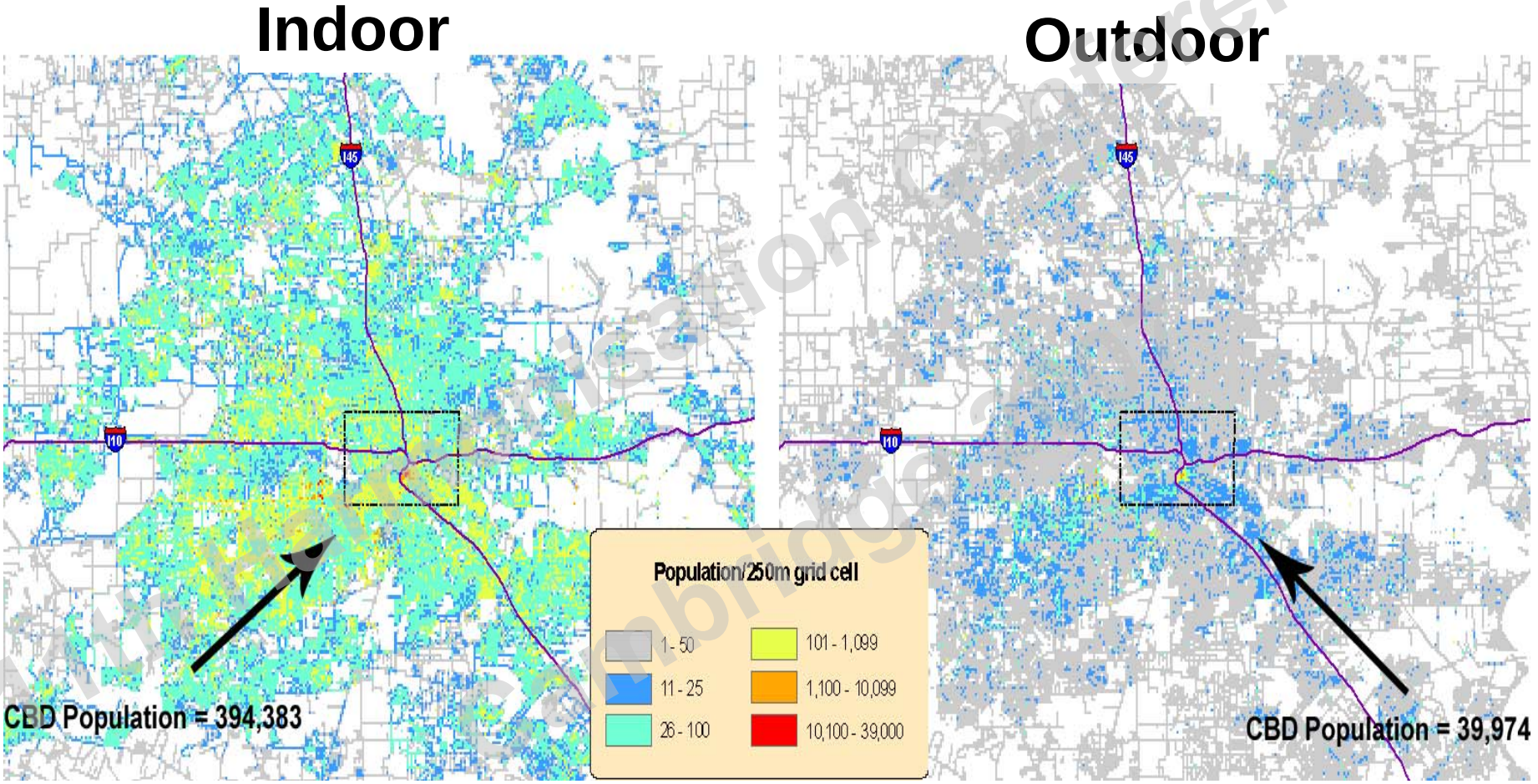
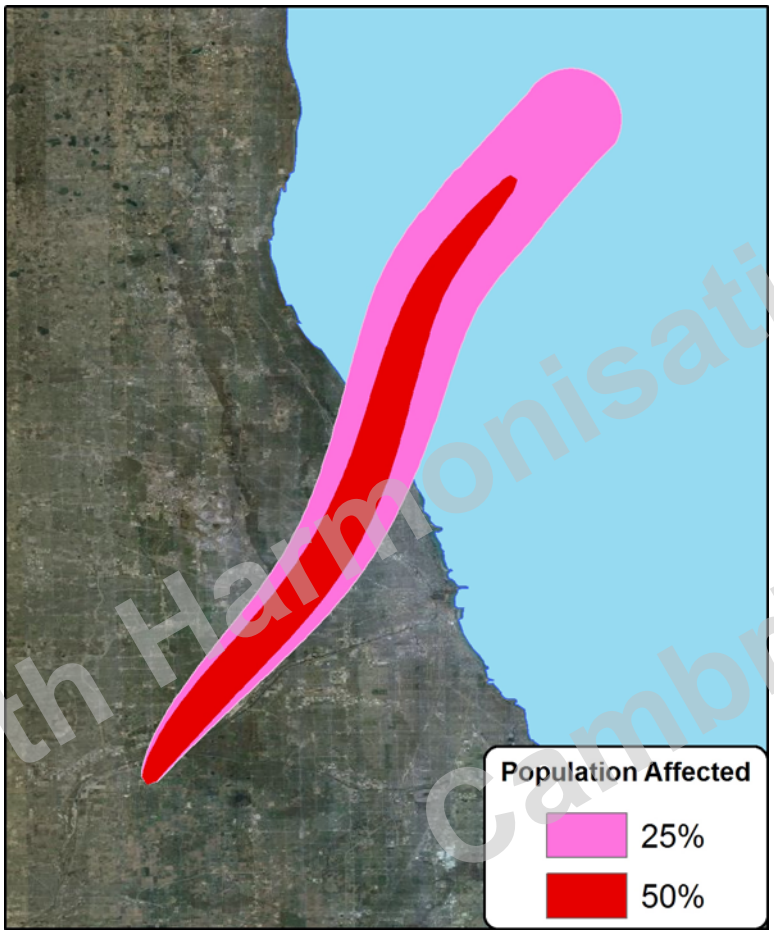
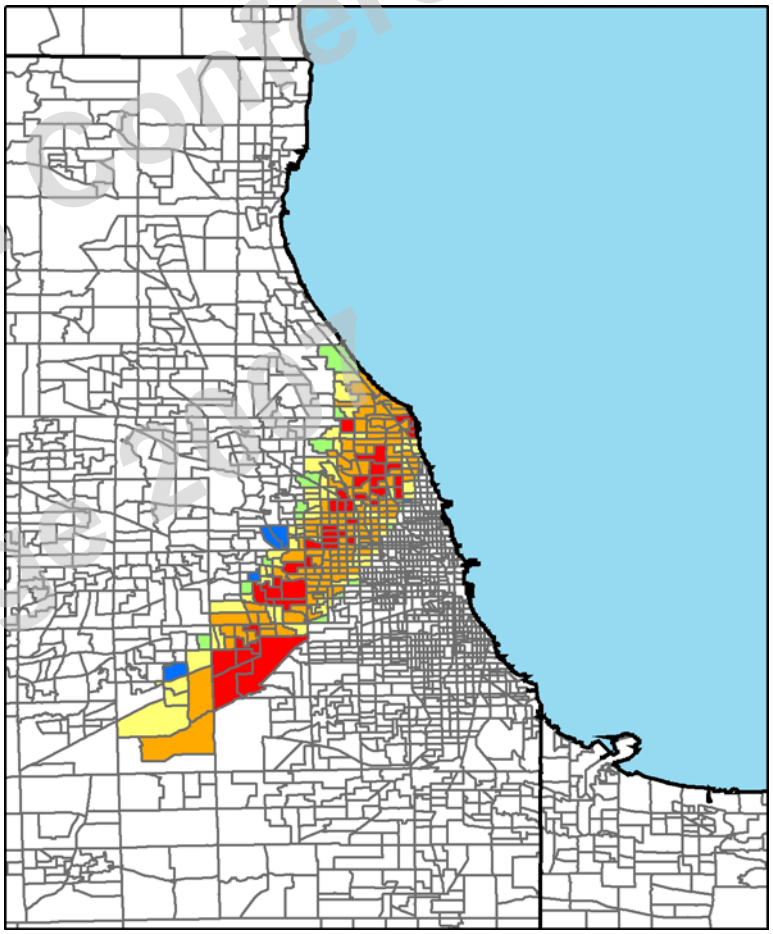
Houston TX Daytime Population

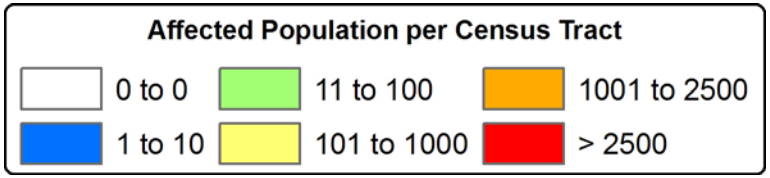


Entire USA available at 250 m grid resolution for both day & night (courtesy of M. Brown)

Population Mobility Matrix







Given a hypothetical release, we can overlay dosage contours on the day-night population.

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Next steps

- **Urban LULC vs. gridded UCP – how do we reconcile the different data requirements for fine-scale modeling in urban areas?**
- **Incorporate advanced UCP derivation approaches using remote sensing data**
- **Explore more accurate multivariate approaches to the current means for extrapolation of UCP by land use alone for data void regions e.g., land use-population based extrapolation tool**
- **Identify and create additional parameters needed by other models**
- **Improve upon current LULC schemes**
- **Maintain and improve service of NUDAPT to community**
- **Your interest, collaboration and comments always sought**

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The End

Thanks for your attention

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Disclaimer: ***The research presented here was performed under the Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and under agreement number*** **DW13921548***. This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views.***