National Urban Database and Access Portal Tool, NUDAPT

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Abstract

Based on the need for advanced treatments of high resolution urban morphological features (e.g., buildings, trees) in meteorological, dispersion, air quality and human exposure modeling systems for future urban applications, a new project was launched called the National Urban Database and Access Portal Tool (NUDAPT). NUDAPT is sponsored by the U.S. Environmental Protection Agency (USEPA) and involves collaborations and contributions from many groups including federal and state agencies and from private and academic institutions here and in other countries. It is designed to produce and provide gridded fields of urban canopy parameters for various new and advanced descriptions of model physics to improve urban simulations given the availability of new high-resolution data of buildings, vegetation, and land use. Additional information include gridded anthropogenic heating and population data is incorporated to further improve urban simulations and to encourage and facilitate decision support and application linkages to human exposure models. An important core-design feature is the utilization of web portal technology to enable NUDAPT to be a "Community" based system. This web-based portal technology will facilitate customizing of data handling and retrievals (http://www.nudapt.org). This article provides an overview of NUDAPT and several example applications.

Capsule:

NUDAPT is a new web-served community-based urban database system designed to be a resource to facilitate implementations of a new generation of advanced urban meteorological, air quality and climate modeling systems.

I. Introduction

Current mesoscale weather prediction and microscale dispersion models are limited in their ability to perform accurate assessments in urban areas. A project called the National Urban Database with Access Portal Tool (NUDAPT) is beginning to provide urban data and improve the parameterization of urban boundary-layer processes (Ching, 2007). The impetus for NUDAPT came from results of an American Meteorological Society Board of Urban Environment survey and recommendations from the Office of the Federal Coordinator for Meteorology's Urban Environment Workshop (2005). Recognizing the need to address issues ranging from the prediction of exposure to a deadly toxic release to the assessment of health risk from poor air quality in urban areas, NUDAPT was initiated by the United States Environmental Protection Agency (USEPA) and supported by several Federal and State agencies and private and academic institutions. NUDAPT will fill a critical gap to provide refined and specialized information to fulfill the operation needs of new urban models (Dupont et al., 2004; Chen et al., 2006, 2007a) and for running their applications (Chen 2007 b, c; Taha (2008a, b, c). NUDAPT builds on the emergence of

- new science and model advancements for urban meteorology modeling,
- new data sets that include
  - newly acquired high-resolution building data for most large cities in the United States;
  - evolving description and resolution of urban land uses and cover data;
  - gridded daughter products, including urban canopy parameters (UCPs) derived from the high-resolution building and vegetation data; and
  - ancillary data, including gridded day and night population and anthropogenic heating; and
- new technology to facilitate NUDAPT's dissemination to and usage by the modeling community with Web-based data access tools in a centralized database.

NUDAPT is a database and decision support system that is hosted in a Geographic Information System (GIS) environment on an ArcGIS server at the University of North Carolina at Chapel Hill. In concept, NUDAPT offers a central Cyber location for users (researchers, analysts, modelers, and policy makers) to access high resolution urban scale data, collected by conventional and remote sensing measurements, that are needed to characterize and model the urban atmosphere. Currently, NUDAPT hosts such data for 33 cities in the United States with different degrees of coverage and completeness. Data are presented in their original format such as building heights, day and night population, vegetation data, and land-surface temperature and radiation, or in a “derived” format such as the UCPs which are used in urban meteorology and air quality modeling applications. As an open source public domain portal, NUDAPT is designed with tools for users to share data, exchange information, discuss results and post their findings, papers and conference presentations.

II. Urban modeling

NUDAPT will provide data for model development and applications in urban areas. Meteorological models provide information needed for planning and conducting air quality assessment and for transport and dispersion of air pollutants and hazardous toxic agents. Mesoscale models generate meteorological fields used for near-surface transport predictions based on surface roughness (Z_o), and stability (Monin-Obukov length) parameters for the primary land use of each model grid. However, for many urban applications, greater spatial detail and fidelity of the flow fields will be required. Recent advances in urban meteorological models now account for the influence of buildings, trees, and other morphological features on the urban boundary layer flows. Gridded UCPs used in the models represent the geometrical characteristics of the morphological features to incorporate the influence and complexities of spatial distributions of building densities and of buildings of different shapes, sizes, and material composition, as well as other dominant urban features (Fig 1). Aerial surveys are now generating geospatial data that capture, with high definition (1 to 5 m), the three-dimensional geometry of individual and conglomerates of buildings and vegetation in urban areas from which model UCPs can be derived (Burian et al., 2004, 2006, 2007a,b) (Fig 2).

Urbanization schemes have been introduced into the Mesoscale Model, Version 5 (MM5), the Weather Research and Forecasting (WRF) and other models and are being tested and evaluated for grid sizes of order 1 km or so (Dupont et al., 2004; Chen et al., 2004, 2007a,b,c; Otte et al., 2004; Chin et al, 2005). The governing equations (introduction and implementation of canopy-layer parameterizations) for each system were modified, and unique sets of UCPs were introduced to represent their urbanization (Table 1 and Fig 2). Current urbanized versions of MM5 and WRF employ slightly different land use schemes. For MM5, an urbanized land-surface model, SM2U (Fig 3), also was introduced to remove limitations of both the dominant land use scheme and the limited (one or two urban classes) classification schemes of the standard MM5 version. In WRF the Noah land surface model (Chen and Dudhia, 2001; Ek et al., 2003), one of three options for land-surface physics, was coupled to a single urban canopy model [Kusaka et al., 2001]) and is applied to urban areas.

Computational fluid dynamics (Coirier et al., 2005; Huber et al., 2004) and fast-response urban dispersion models (Brown, 2004) now also are capable of modeling flows around buildings, and all require detailed information of the urban morphology, especially the building geometry. Other applications (Cionco and Ellefson, 1998) require information at a scale of 50 to100 m, which falls intermediately between the meso-urban (1 km) and the 1- to 10-m-sized building scales. Transport simulations at this scale based on objective analyses schemes require high resolution bare-earth digital elevation data and specialized urban morphological data including geometry and material characteristics of individual buildings and density and porosity and roughness of groups of buildings.

III. Features and components of NUDAPT

A. Community design concept and features

NUDAPT utilizes web-based portal technology to enable a community-based modeling resource for handling the databases and for facilitating collaboration. The database is a repository of multiple, heterogeneous datasets that all adhere to a consistent format and metadata specification, and allows for science knowledge integration and an efficient means of sharing and performing detailed analysis. The database system operates at two levels. First, datasets of high-resolution full feature digital terrain elevation containing the three-dimensional representation of urban morphological features (e.g., buildings and trees) and extracted building footprints and geometries reside at the lowest layer. The portal manages accessibility to this layer to preserve and maintain, as necessary, proprietary and other sensitive status requirements and for managing the network bandwidth burden. Processed data, including computed UCPs, are in other layers at this level. The second level contains tools and capabilities for general community usage. Here, users can query the database for relevant data, process and retrieve data in a form that is best compatible with their specific modeling requirements, and submit additional information to the database. Users of NUDAPT are encouraged to enter a cycle of inquiry, usage, and improved insights to enable the improvements-to-modeling dividends.

The portal allows researchers the ability to search through indices of relevant datasets. It handles Web-based data extraction and conversion in both raster and vector formats. The Environmental Systems Research Institute's (ESRI) relatively new ArcGIS Server provides a single engine with many desirable functions that are needed to handle raster and vector data. ArcObjects Java is the preferable language, thus, if the server-side processing demand becomes severe, the application easily can be ported to a high-performance Linux environment.

B. Databases

NUDAPT has been populated with a wide array of databases critical to accurate urban modeling. Three-dimensional buildings data based upon airborne light detection and ranging (LIDAR) signals that produce full-feature digital elevation and terrain models (DEM, DTM), micrometeorological database, gridded UCPs, population, anthropogenic heating, and land use/land cover are the core databases incorporated within NUDAPT to date.

1. High-resolution building data

Data on buildings, their size, shape, orientation, and relative location to other building and urban morphological features (trees, highway overpasses, etc.) are now available for the largest urban areas in the United States. The emergence of these heretofore unavailable datasets has stimulated the use of urban canopy parameterizations in mesoscale meteorological modeling because of the possibility of deriving the necessary UCPs. Building databases, in general, can be extracted from paired stereo-graphic aerial images by photogrammetric analysis techniques or from DTMs acquired by airborne LIDAR data collection. LIDAR data are acquired by flying an airborne laser scanner over an urban area and collecting return signals from pairs of rapidly emitted laser pulses. The laser returns are processed to produce terrain elevation data products, including full feature DEMs and bare-earth DTMs. The morphological properties of buildings and trees (e.g., height, footprint extent) can be determined by subtracting the DTM from the DEM to produce a database of heights above ground level. The maximum resolution is determined from a combination of aircraft speed and laser pulse rates and, typically, is of the order of 1 to 5 m. LIDAR is especially enticing because it provides a high-resolution representation of urban morphological features, especially buildings and trees, for entire metropolitan areas, with a minimal set of airplane flyovers. However, LIDAR is costly and presents a data management challenge given the massive size of datasets.

For example, the Houston, TX, prototype constructed in NUDAPT now contains 1-m and 5-m DEM and DTM databases for a large section of the Houston metropolitan area based on a 2001 LIDAR flyover (see next section). In general, a variety of automated and semi-automated approaches to extract building and tree objects from the LIDAR-based DEM and DTM have been developed and provide building and tree data coverage in vector format for large parts of most of the major cities in the United States.

For the Houston prototype a 650,000-building geographic information system dataset has been incorporated.

NUDAPT contains archived copies of LIDAR DEM and DTM data currently being acquired by the National Geospatial Agency (NGA; formerly the National Imagery and Mapping Agency). When completed, NGA will have obtained data from as many as 133 urban areas. That project is part of the Homeland Security Infrastructure Program (HSIP); the Nunn-Lugar-Dominici Act (Defense Against Weapons of Mass Destruction Act of 1996) established a project in which the U.S. Department of Defense was tasked to help respond to chemical, biological, and nuclear incidences in the 133 urban centers. This data (together with the National Map Project of the U.S. Geological Survey [USGS]) provide a critical infrastructure information base for HSIP. With copies of such data for most major cities in the United States, NUDAPT will provide the basis for deriving urban modeling parameters on a national scale.

2. Morphology and urban canopy parameters

As indicated earlier, in addition to roughness and bulk scaling parameters, a variety of geometrical and density descriptors of urban morphological features now is being introduced into advanced urban models (Table 1). For the Houston prototype, as an example, the UCP database provides 250-m and 1-km resolution coverage of UCPs. These parameters have been calculated for each grid in the modeling domain based on the 650,000-building database integrated with the LIDAR DEM and DTM (Burian et al., 2004). Fig 2 shows examples of morphological and geometrical parameters used in the MM5 gridded fro 1-km cells for Houston. Clearly, each grid cell has a unique set of

UCPs describing its building, vegetation, and land use features; consequently, each cell has a unique influence on the resulting model simulation. The WRF model utilizes a different set of UCPs (Table 1) for its single layer urban canopy version (Kusaka et al., 2001; Chen et al., 2006, 2007a, b, c). At this time UCPs have been derived for 44 cities under a DHS sponsored Urban Database project (Burian et al., 2007c).

3. Anthropogenic heating and population data

Energy usage is concentrated but not evenly distributed in urban areas. In some areas, the heat that is generated can be a significant fraction of the overall energy budget in the urban area, and this contribution varies both spatially and temporally across the city. Gridded fields of this energy component would replace the oversimplified fields based on gross assumptions that typically are used in operational models. NUDAPT now includes anthropogenic heating (AH) as one of its priority variables. Gridded values of AH at 500-m resolution (Fig 4) now in NUDAPT have been prepared using methodology developed by Sailor and Lu (2004), Sailor and Hart (2006) for representative summer and winter days. Results of a sensitivity study utilizing gridded AH in NUDAPT are shown below.

The NUDAPT prototype also contains daytime and nighttime populations gridded at 250 m according to McPherson and Brown (2003) and shown in Fig 5a (Houston) and Fig 5b (national map of database). The nighttime data is based on the 2000 Census and is modified to account for population near roads; the daytime represents worker and daytime residential populations based on the State Business Directory and the Census Transportation Planning Package data sets. At this time, it does not include the traffic, shopping, school special events and tourist populations. Nonetheless, the current population data along with urban concentration fields would be a powerful set of information for conducting assessment studies of exposures ranging from agent releases to air pollutant “hot spots”.

C. Portal features

The NUDAPT portal system provides urban database and support tools to be applied to advanced urban modeling systems. It uses a Web-based tool, Quickplace, that provides an environment designed to foster future research and development collaborations to advance the state of science of urban modeling. The current prototype portal delivers server-side data processing (thus minimizing or eliminating the need for desktop geographical information systems) and provides a responsive map viewer for data exploration of the source and gridded datasets. Tools are available to clip, reproject, resample, reformat, and zip subsets of the data. The clip tool allows several choices for selecting a subdomain, either by using a bounding box envelope projected into spatial reference of raster and output or by specifying coordinates. The reprojection tool allows datasets to be referenced into various user-specified coordinate systems. Currently, NUDAPT supports many coordinate reference systems (all NAD83 including spherical, latitude/longitude, UTM, and Albers Equal Area) for its outputs; however, with the ESRI Library, hundreds of custom projections are also possible. NUDAPT users will have several methods to perform resampling to retain to the extent possible the unique properties of the data from the base projection. Currently options include nearest neighbor, bilinear interpolation, and cubic convolution methods. For maximal conservation of the data properties, NUDAPT users also can invoke the so-called "spatial allocator" tool (Eyth and Brunk, 2007). Several output formats are available for zipping and downloading of user customized datasets including NetCDF, ASCII, Floating Point, Imagine Image, and GeoTiff.

IV. NUDAPT prototype

Houston was selected to serve as the NUDAPT prototype. This prototype includes a set of LIDAR-derived building data, sets of gridded daughter products (UCPs), anthropogenic heat fluxes, and day-night population data. For the prototype, demonstration applications utilized urbanized versions of MM5, WRF, and EPA's Community Multiscale Air Quality (CMAQ) modeling system for the TEXAS 2000 intensive field study (http://www.utexas.edu/research/ceer/texaqs/). Houston is the fourth most populous city in the United States; large amounts of oxidant precursors are introduced there from traffic, and large amounts of air toxic pollutants are emitted from its ship channel area, thus contributing to poor air quality. Modeling was performed using nesting methods in which boundary conditions are provided sequentially to domains of each subsequently finer grid mesh. Given the proximity to Galveston Bay, hourly observed sea surface temperatures were introduced to increase the accuracy of simulating the bay-land breeze flow reversal in the Houston area. Examples showing sensitivity of employing NUDAPT-supplied parameters against base case simulations that utilize a standard set of parameters are illustrated below.

A. Urbanized MM5 and CMAQ simulations

Fig 6 compares model simulations of predicted dispersion parameters for Houston on August 30, 2000. The standard set employs a single urban land use class of the USGS classification scheme for Houston. In contrast, the urbanized canopy version of MM5 employs additional urban land use classes and UCPs that reflect buildings and vegetation data (see Table 1 [Dupont et al., 2004]). As a result, intra-urban spatial gradients in the metropolitan area of Houston are negligible in the standard implementation in contrast to results from the urbanized version. Both sets of meteorology were used to simulate air quality using EPA's CMAQ modeling system (Byun and Schere, 2006), the results exhibited significant differences in magnitude and spatial patterns for ozone (Fig 7). These simulations show the effect of ozone titration by elevated levels of nitrogen oxide (NO_x), primarily from mobile source contributions. (Simulations performed at 4-km grid size exhibited considerably reduced levels of NO_x and a concomitant reduction in titration effects on ozone.)

B. Sensitivity studies using urbanized WRF

The urbanized WRF model (V2.2) was used to conduct sensitivity experiments using NUDAPT; for this study, this version of WRF was configured with four two-way interactive nested grids having grid spacing of 27, 9, 3, and 1-km. There were 31 vertical levels with 16 levels within the lowest 2 km in the atmosphere to better resolve the atmospheric boundary layer. It was initialized at 00 UTC 30 August 2000 with National Center for Environmental Prediction's Environmental Data Assimilation System and integrated for 36 hours, and used the following physics options: Dudhia's shortwave radiation scheme, Rapid Radiative Transfer Model longwave radiation scheme, Mellor-

Yamada-Janjic PBL scheme, and the NOAH land-surface model with one-layer urban canopy model (UCM). Model studies testing the sensitivity to model inputs of morphological properties of buildings and other roughness features, land cover, and anthropogenic heating rate data from NUDAPT and look-up table values for WRF have been performed. WRF-simulated shelter (2-m) temperature differences between using the NUDAPT anthropogenic heating rate and using table-based anthropogenic heating rate are shown in Fig 8b, (corresponding differences in daily anthropogenic heating rate are shown in Fig. 8a). Note that employing table look-up values for those parameters already represent a significant modeling improvement over the nonurbanized WRF versions. Results show differences reaching 1.5° C; differences were also noted for wind speed and mixing heights. We have surmised that the use of actual building data and anthropogenic heating do affect the accuracy and precision of the simulations of surface meteorological variables and mixing heights, consistent with the experience with the urbanized MM5 model.

C. Urban heat island (UHI) modification studies

Another example application of UCP meteorological models and related morphological data is in studying urban heat islands and their mitigation (Taha and Ching, 2007). Heat islands are a phenomena associated with urbanization. Their intensity is influenced primarily by the complexities in the radiation properties of buildings and urban canyons and morphological features, the degree of surface imperviousness and soil moisture availability, enhanced thermal heat storage capacity, and the introduction of anthropogenic sources of heat (Taha 1996, 1997). Taha (2008a, b) conducted modeling experiments to investigate the potential for mitigating UHIs and to study their air quality consequences. Using his urbanized version of MM5 in an application to Sacramento, California (Taha 2008c), he showed temperature reductions from vegetation and albedo change in excess of 1 degree C each from its base case was achievable (Fig 9). When such results were applied to an air quality model, e.g., CAMx in this case, it produced a decrease in ozone of the order of 10 ppb_v (Fig 10). These results illustrate the potential for applications using NUDAPT for performing urban planning study simulations that alter the urban landscape with the goal of reducing adverse impacts on air quality, visibility, and comfort in urban areas (Taha, 2008a).

V. Summary

NUDAPT was developed to provide to the modeling community a resource to facilitate addressing many of the evolving environmental problems of urban areas. It features a database with high-resolution urban morphological features and specialized daughter products representing the geometry, density, material, and roughness properties of the morphological features. The Houston Prototype example presented herein is extensible to most urban centers in the US because datasets containing their morphological features, and in some cases derived building information, is available. The community now is invited to use NUDAPT for advanced applications, including improved urban climate predictions, advanced atmospheric dispersion modeling, assessment of exposure to airborne hazards for populations in transit throughout the day, and human exposure assessment of air quality (http://www.nudapt.org).

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Figure Captions

Figure 1: Schematic of urban canopy parameterization concept and methodology. Here, sky view factor is the ratio of the radiation received in the street canyon to the hemispheric radiation above the canopy.

Figure 2: Selected urban canopy parameters (UCPs) derived for 1-km^2 cells for Harris County, TX, as used in the urbanized MM5 modeling system. PAD is plan area density, and FAD is frontal area density of the buildings in each cell. Note that each cell has a unique combination of UCPs.

Figure 3: Schematic showing the urbanized version of MM5 based on DA-SM2U (Dupont et al., 2004). Drag force approach is used in contrast to the standard roughness approach. Street canyon radiative fluxes are included as shown in left hand side panel, and a land surface model, SM2U provides for within-grid variations of fluxes.

Figure 4: Example of maximum anthropogenic heat fluxes (Q_f) gridded at 500 m on hourly basis in NUDAPT, based on method by Sailor et al. (2004). Example shown is for Houston, TX, for a “typical” day in August at 2000 UTC.

Figure 5: Daytime and nighttime population for (a) central Houston, TX, gridded at 250-m resolution and (b) the CONUS coverage of both day and night population data in NUDAPT. Nighttime maps are derived from Census 2000; and daytime values are based on worker population (processing methodology based on McPherson and Brown, 2003).

Figure 6: Examples from model sensitivity study showing sensible heat fluxes and PBL height for MM5 simulations at 1-km grid size using urbanized version (DA-SM2U) of Dupont et al. (2004) and standard version for 2000 UTC, August 30, 2000. Standard version uses single (urban) land use category for all of Houston, TX.

Figure 7: Example results of ozone simulations based on CMAQ model driven by urbanized (UCP) versus standard version (NoUCP) of MM5 at 1-km grid size for Houston, TX, at 2100 UTC, August 30, 2000.

Figure 8: a) Difference of daily mean anthropogenic heating rate (W/m^2) for Houston: WRF/UCM lookup table - NUDAPT data; b) 2-m air temperature differences (K) at 1200 UTC on 30 August 2000 between the WRF simulation that used WRF/UCM table-based anthropogenic heating rate and the simulation that used NUDAPT anthropogenic heating rate.

Figure 9: Results of nested model experiments for Sacramento, CA; uMM5, an urbanized version by Taha (2008c) was applied to domain indicated by the small white box near the center of D02. Results illustrate the capability of simulating urban heat

island (UHI) and the potential for mitigation as simulated temperature difference (cooling) at the surface as a result of increased urban albedo.

Figure 10: Sensitivity of air quality (ozone) to UHI reduction scenarios described in Figure 9 (Taha 2008a,c).

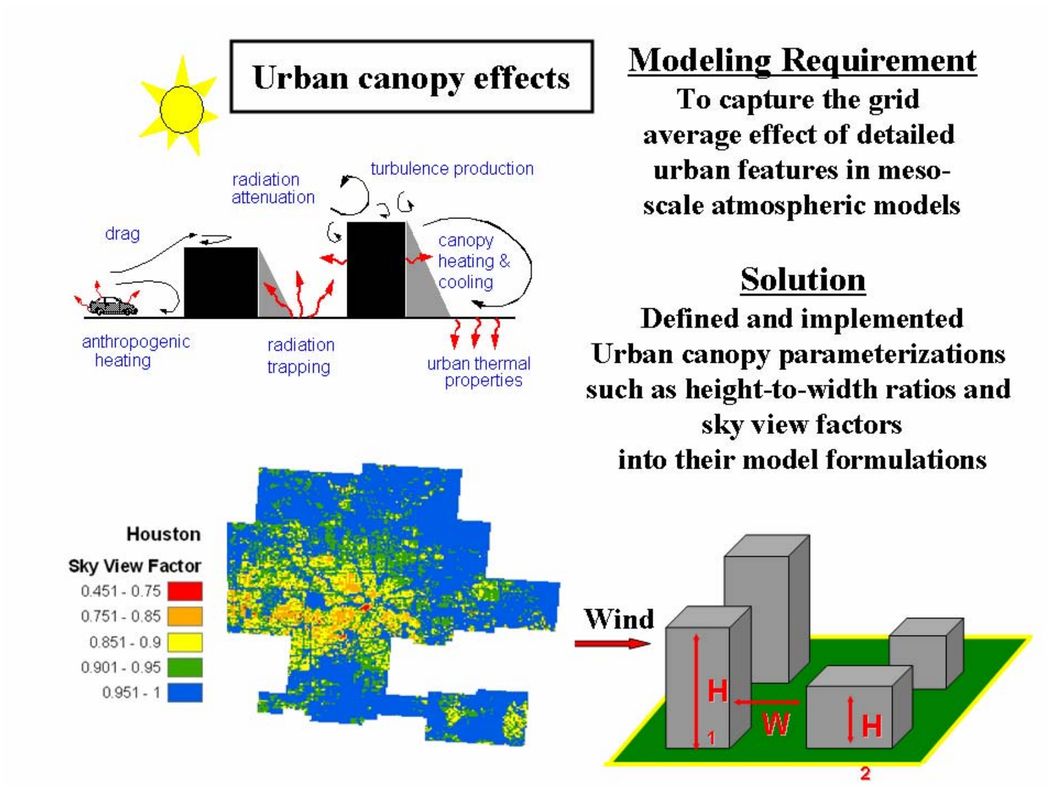


Figure 1: Schematic of urban canopy parameterization concept and methodology. Here, sky view factor is the ratio of the radiation received in the street canyon to the hemispheric radiation above the canopy.

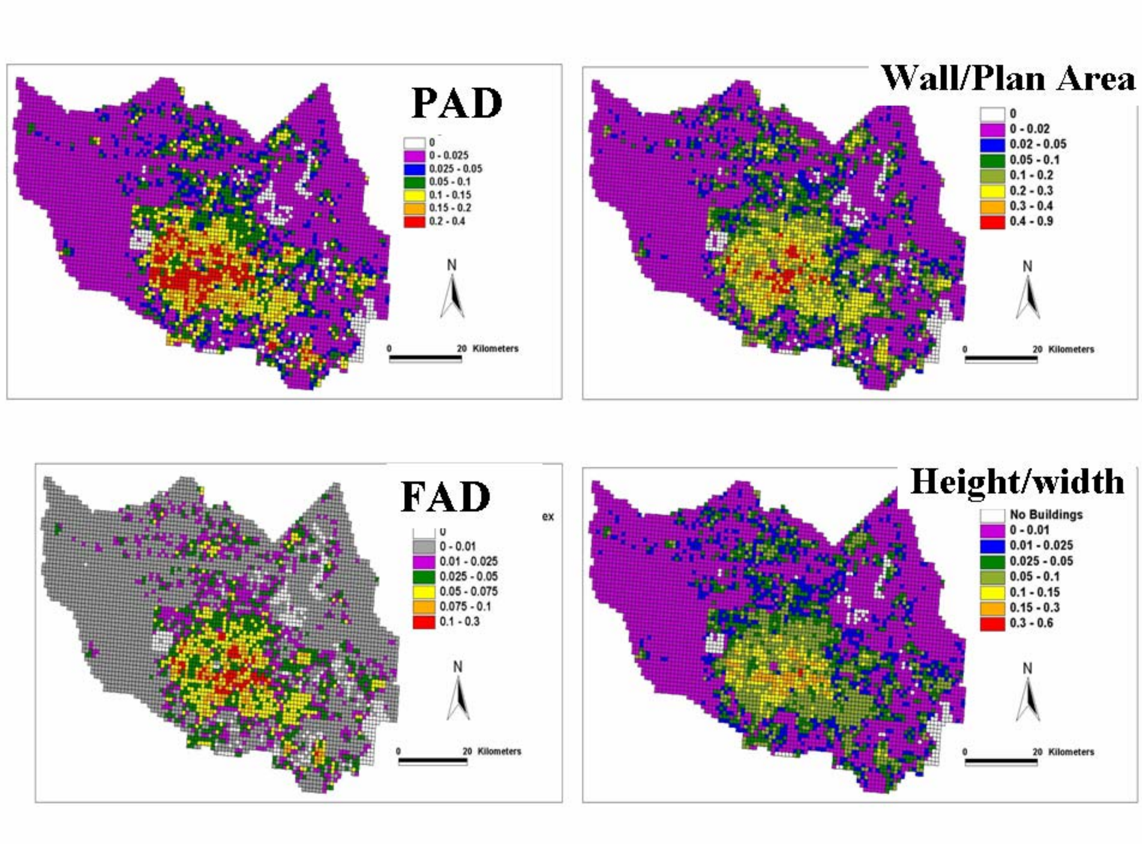


Figure 2: Selected urban canopy parameters (UCPs) derived for 1-km^2 cells for Harris County, TX, as used in the urbanized MM5 modeling system. PAD is plan area density, and FAD is frontal area density of the buildings in each cell. Note that each cell has a unique combination of UCPs.

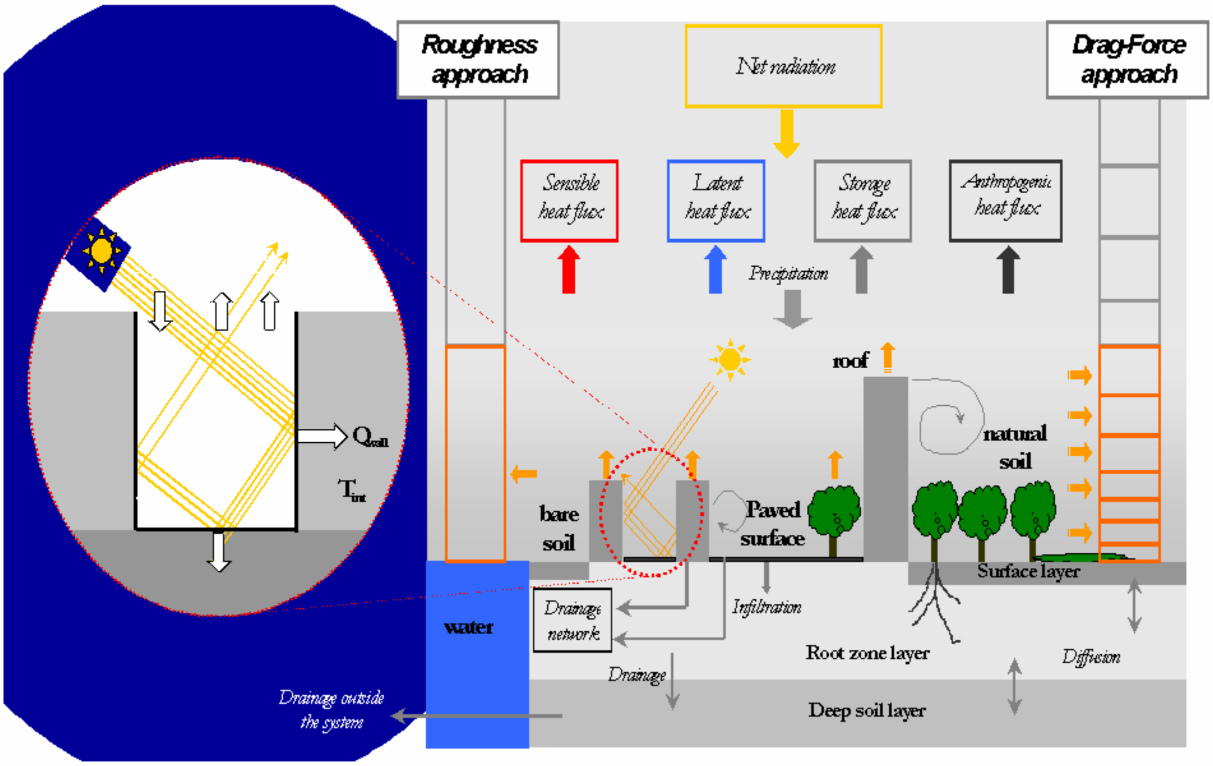


Figure 3: Schematic showing the urbanized version of MM5 based on DA-SM2U (Dupont et al., 2004). Drag force approach is used in contrast to the standard roughness approach. Street canyon radiative fluxes are included as shown in left hand side panel, and a land surface model, SM2U provides for within-grid variations of fluxes.

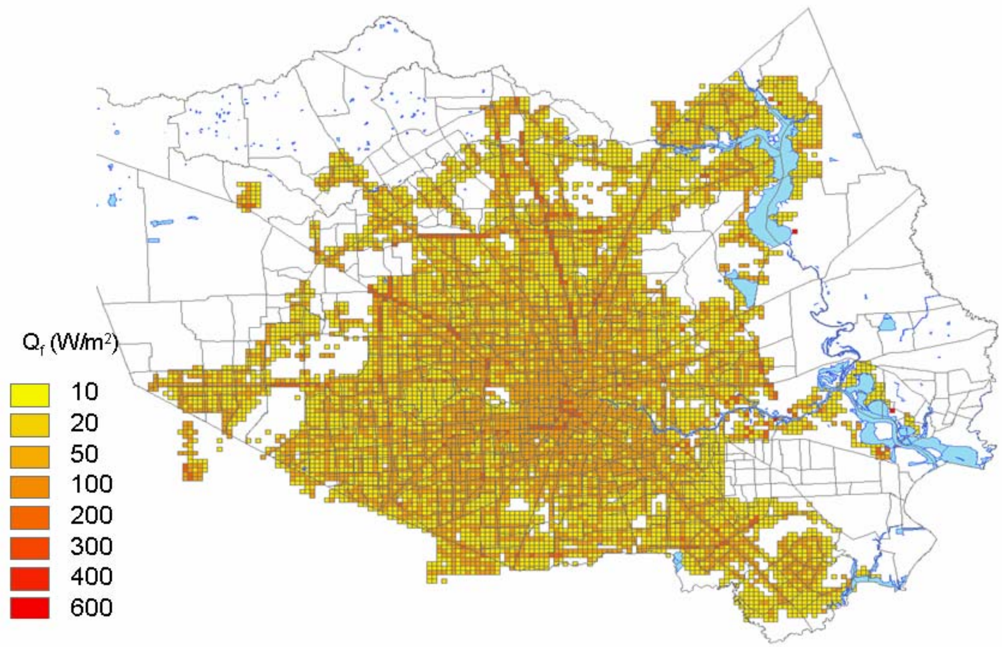


Figure 4: Example of maximum anthropogenic heat fluxes (Q_f) gridded at 500 m on hourly basis in NUDAPT, based on method by Sailor et al. (2004). Example shown is for Houston, TX, for a “typical” day in August at 2000 UTC.

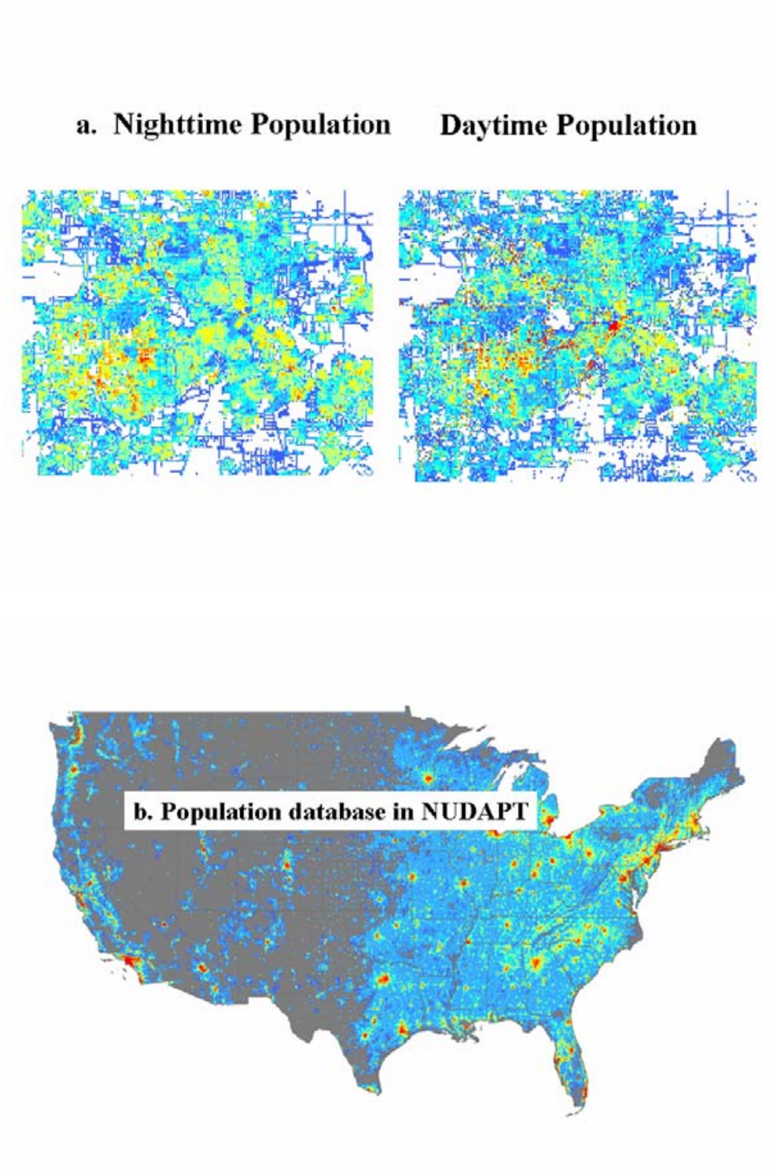


Figure 5: Daytime and nighttime population for (a) central Houston, TX, gridded at 250-m resolution and (b) the CONUS coverage of both day and night population data in NUDAPT. Nighttime maps are derived from Census 2000; and daytime values are based on worker population (processing methodology based on McPherson and Brown, 2003).

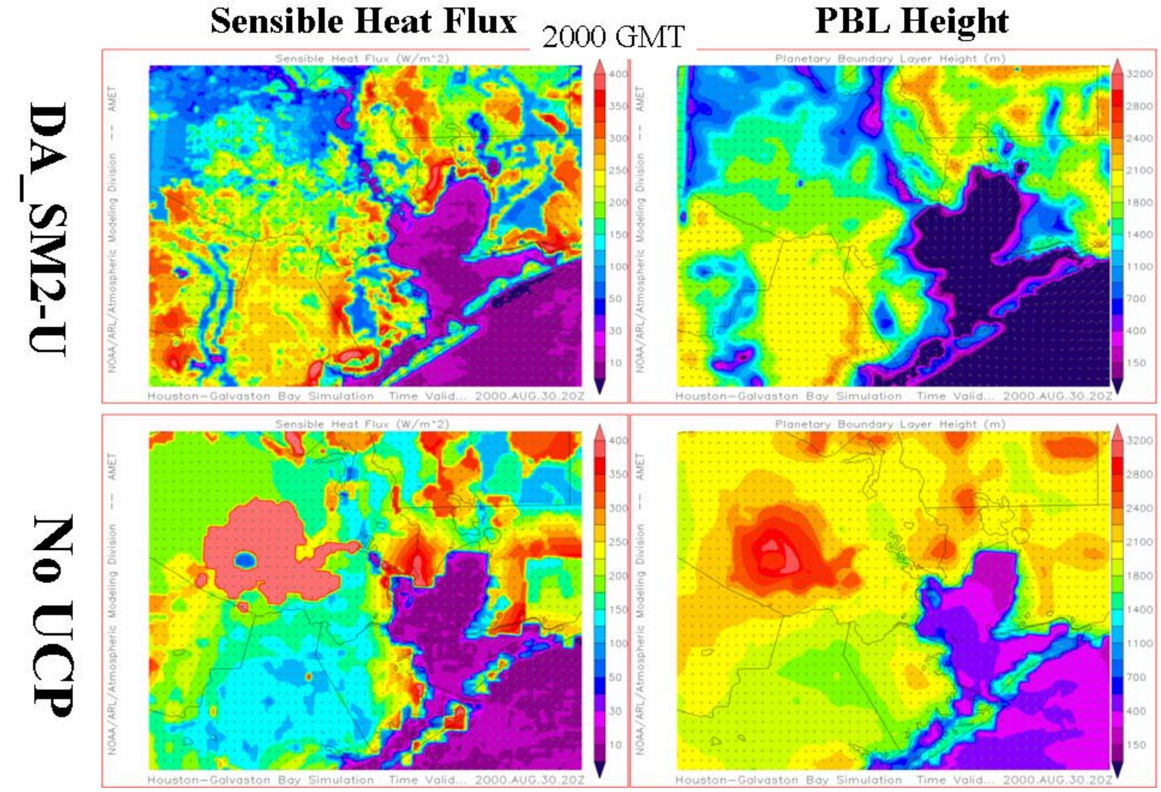


Figure 6: Examples from model sensitivity study showing sensible heat fluxes and PBL height for MM5 simulations at 1-km grid size using urbanized version (DA-SM2U) of Dupont et al. (2004) and standard version for 2000 UTC, August 30, 2000. Standard version uses single (urban) land use category for all of Houston, TX.

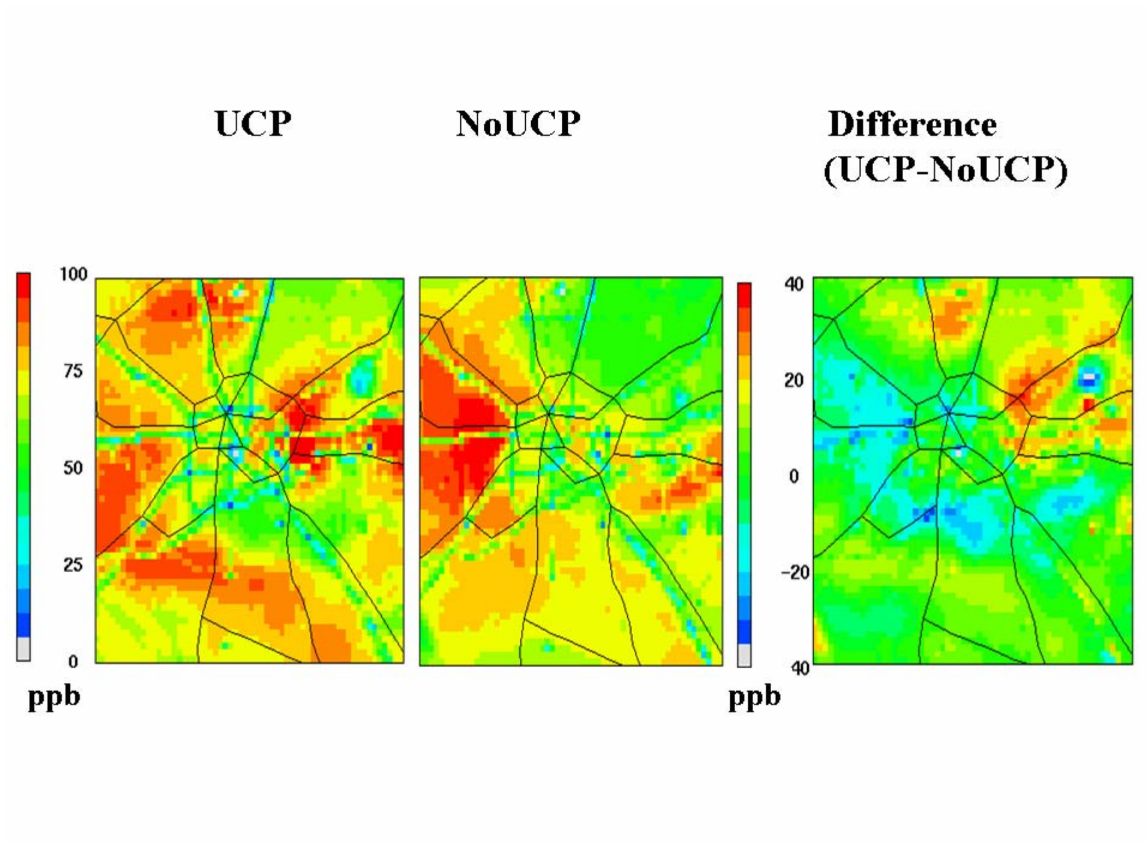
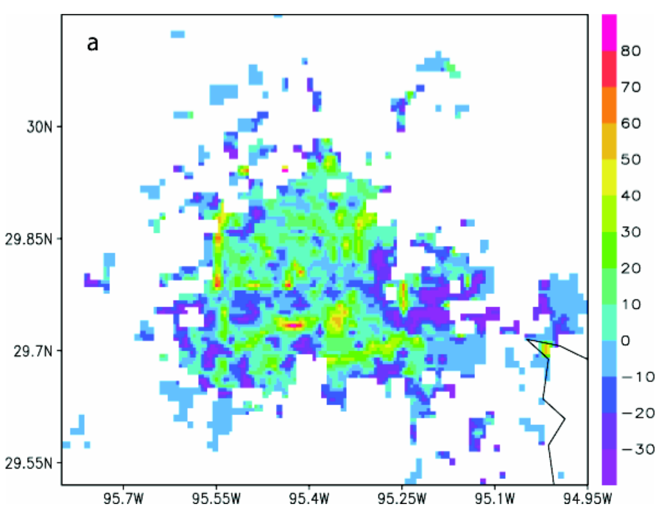


Figure 7: Example results of ozone simulations based on CMAQ model driven by urbanized (UCP) versus standard version (NoUCP) of MM5 at 1-km grid size for Houston, TX, at 2100 UTC, August 30, 2000.



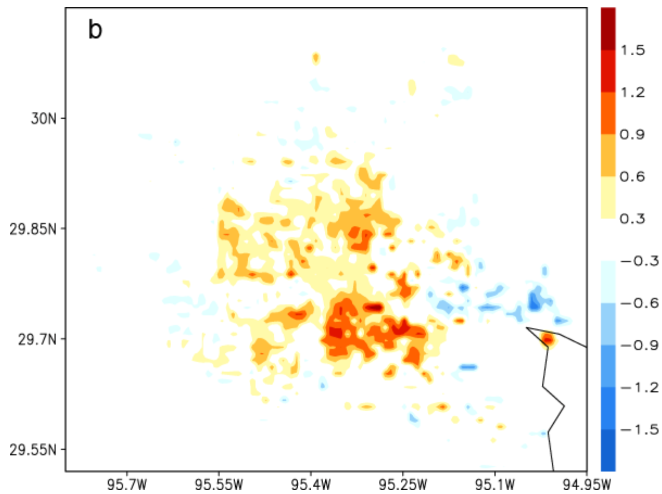
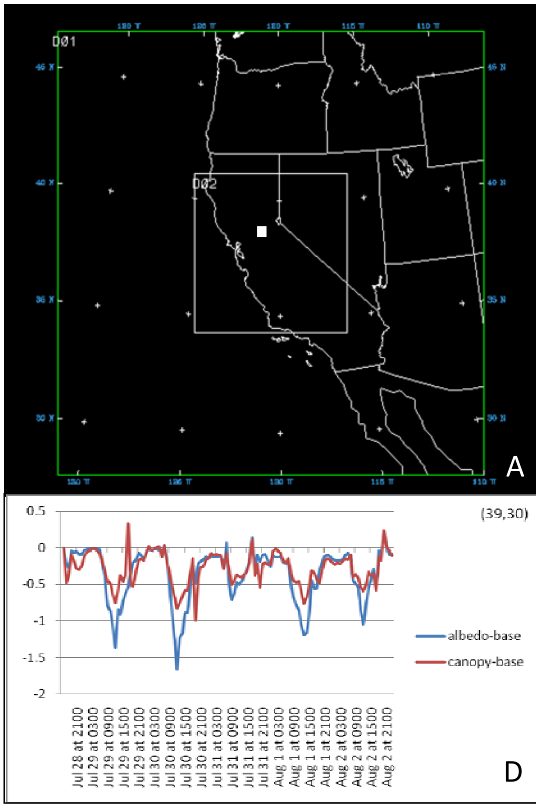
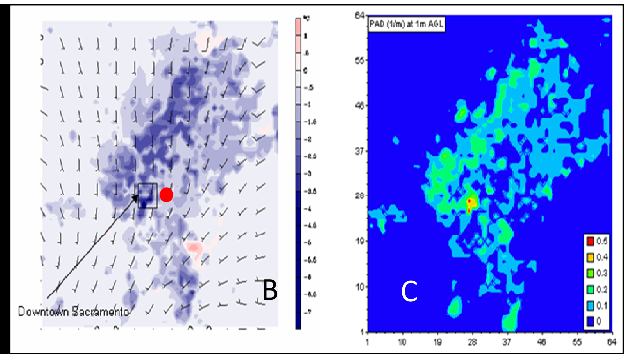


Figure 8: a) Difference of daily mean anthropogenic heating rate (W/m^2) for Houston: WRF/UCM lookup table - NUDAPT data; b) 2-m air temperature differences (K) at 1200 UTC on 30 August 2000 between the WRF simulation that used WRF/UCM table-based anthropogenic heating rate and the simulation that used NUDAPT anthropogenic heating rate.





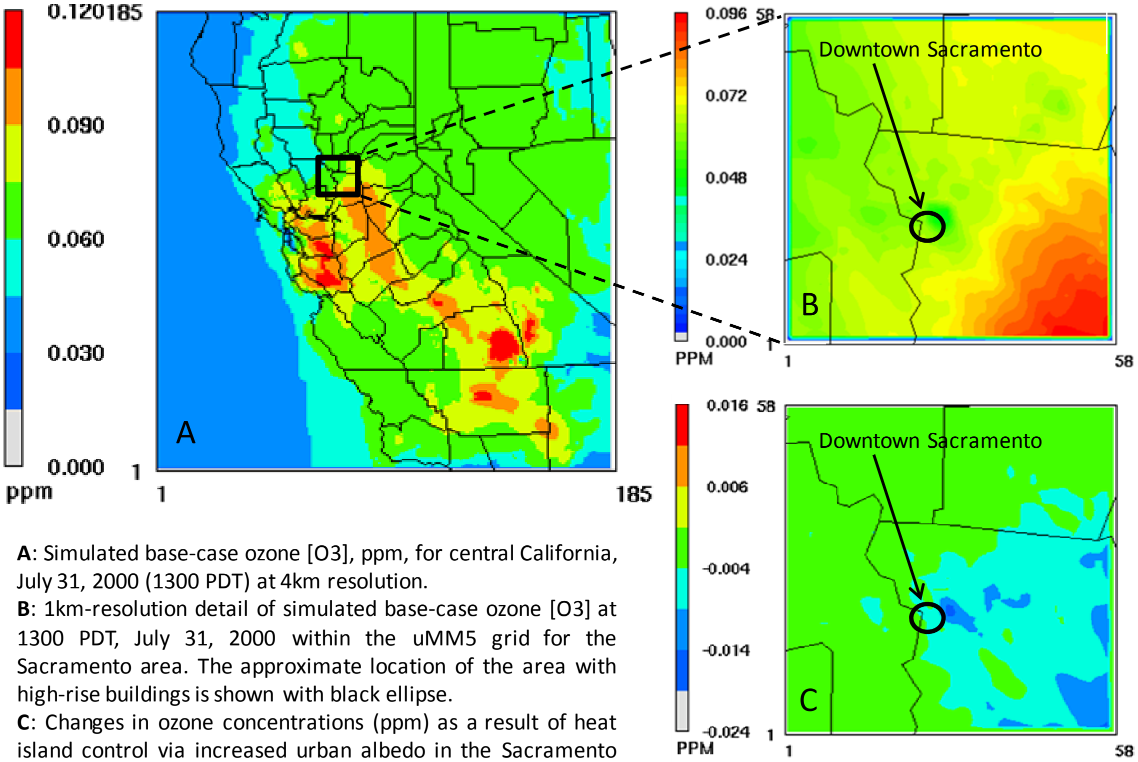
A: Mesoscale (MM5; 12 and 4km) and meso-urban (uMM5; 1km) meteorological simulation domains (Taha 2008a). The small white rectangle indicates the Sacramento-area uMM5 modeling domain which is enlarged and shown in figures B and C.

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).

Figure 9: Results of nested model experiments for Sacramento, CA; uMM5, an urbanized version by Taha (2008c) was applied to domain indicated by the small white box near the center of D02. Results illustrate the capability of simulating urban heat island (UHI) and the potential for mitigation as simulated temperature difference (cooling) at the surface as a result of increased urban albedo.



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.

Figure 10: Sensitivity of air quality (ozone) to UHI reduction scenarios described in Figure 9 (Taha 2008a,c).

Table 1: Urban Canopy Parameters used in MM5 and WRF

MM5

- 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
- Rooftop area density
- 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
- Mean orientation of streets
- Surface fraction of vegetation, roads, rooftops, water and impervious area
- Albedo
- Emissivity
- Building materials

WRF

- Urban fraction
- Building height, ZR
- Roughness for momentum above the urban canopy layer, Z_0C
- Roughness for heat above the urban canopy layer Z_0HC
- 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