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MM5 Simulation study of Urbanization Influences on the Climate of Tokai area, Japan

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Abstract

Evaluating urbanization is necessary to make realistic representation of urban influence on local climate as well as to improve the living environment in urban area. One month numerical simulation has been conducted using NCAR/PSU Mesoscale Model (MM5) during August 2003 to reproduce the local urbanized meteorological fields in Tokai area. A newly classified land cover to account for the heterogeneity of the urban area in Nagoya using LANDSAT +ETM satellite images, a simple modification by including sky view factor and anthropogenic heat are introduced in MM5. Three different locations have been chosen in urban, suburban and rural area to investigate the land cover effect on near surface temperature and surface energy fluxes. These simulated data by the modified MM5 with new land cover is validated through comparison with the JMA observation station in urban area. The sensitivity simulations using modified MM5 prove considerable improvement in the near surface temperature and surface energy fluxes in urban area due to urban parameterization in MM5. Large temperature difference between urban and rural areas has produced the heat island phenomenon at the center of Nagoya city. Thus modified MM5 shows better interpretation of urbanization effect on local meteorology because of urban parameterization and land cover classification.

Keywords

Urbanization modification in MM5, land-cover classification, urban heat island

1. General introduction

Urbanization due to its rapid associated changes in land-use pattern (Oke 1982) is worthy of special attention, because the Intergovernmental Panel on Climate Change (IPCC 2001) report confirms the stronger evidence that over the last 50 years global climate change is considerably attributed to human activities.

Climate in a particular area is substantially influenced by urbanization, which defines the land cover characteristics and changes in land-use pattern. Urban surfaces, generally have lower albedo and higher thermal heat capacity, contain large amount of heat and are unable to retain rain water for evaporation. The three dimensional street canyons along high-rise buildings trap solar radiation at day. Vehicles, industries, air-conditioning systems also produce anthropogenic emissions of heat, water vapor and pollutants in atmosphere (Kimura and Takahashi 1991). These alterations influence the absorption of solar radiation, surface temperature, evaporation rate, storage of heat and turbulent wind production and drastically transform the conditions of the near-surface atmosphere. Consequently heat island phenomenon becomes an obvious outcome of climate change in urban area and shows consistently higher temperatures compared to surrounding rural areas as illustrated in Figure 1.1. The effect of heat island is strongest in the city center where large population densely resides. Change in temperature profile along with other meteorological phenomena and high rate of energy consumptions occur due to adverse effect of urban heat island. Whereas in rural area the presence of green surfaces and water body keep lower temperature due to lower thermal heat capacity, presence of moisture and higher latent heat flux.

The Tokai area is a sub-region of Chubu, Japan along Pacific Ocean (Figure 1.2) having mixed land-use characteristics with mountains and forests, seaside plain land with populated commercial, industrial and residential areas. Nagoya is the biggest urban center in Tokai area in respect of population and GDP, which has complex urban

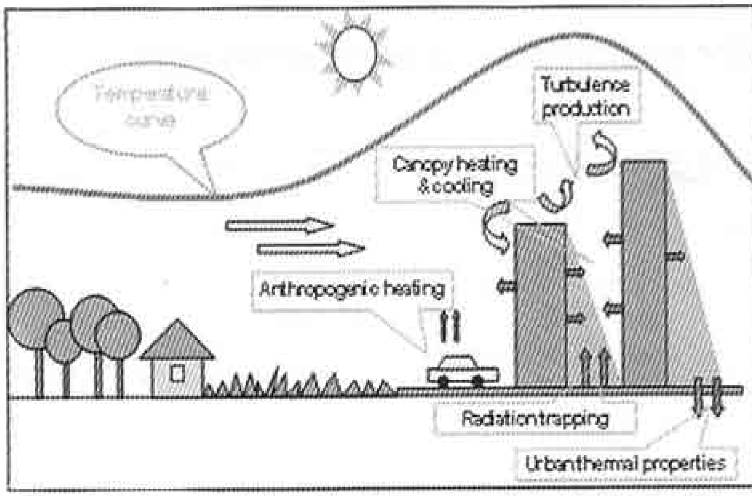


Figure 1.1: Schematic of urbanization influence on climate and heat island effect.

characteristics because of dense urban structures, high traffic flow and highest energy consumption. Nagoya has a central core with commercial zone of large spatial extent beside the Nagoya castle surrounded by mixed commercial-residential areas. Large residential areas of xeric and mesic[1] characteristics are encircled by mixed commercial-residential zone and stretched to the other side of river. This study has focused on urbanization in Nagoya city and its influence on local climate.

Mesoscale atmospheric models are increasingly employed to improve the understanding of processes related to neighborhood scale climate, urban heat island phenomena and mesoscale circulations caused by urban-rural land cover differences. Those processes are strongly influenced by the energy and momentum exchanges between the atmosphere and the underlying surfaces. Several studies have investigated the sensitivity of mesoscale models to idealized land cover scenarios, in particular the abundance of vegetation which was shown to have a significant influence on the simulated near surface temperatures (Taha 1996). This paper is based on study where a classical mesoscale model is applied to investigate the urbanization influence on climate of Tokai area in terms of near surface temperature and surface energy fluxes by characterizing the urban and rural land cover correctly.

1.1 Objectives

The main objective of the study was to investigate the urbanization effect on local meteorological fields in Tokai area using mesoscale model MM5[2]. To accomplish this goal, an urban parameterization was adopted in MM5 to simulate meteorological fields in planetary boundary layer to produce satisfactory result and when compared with

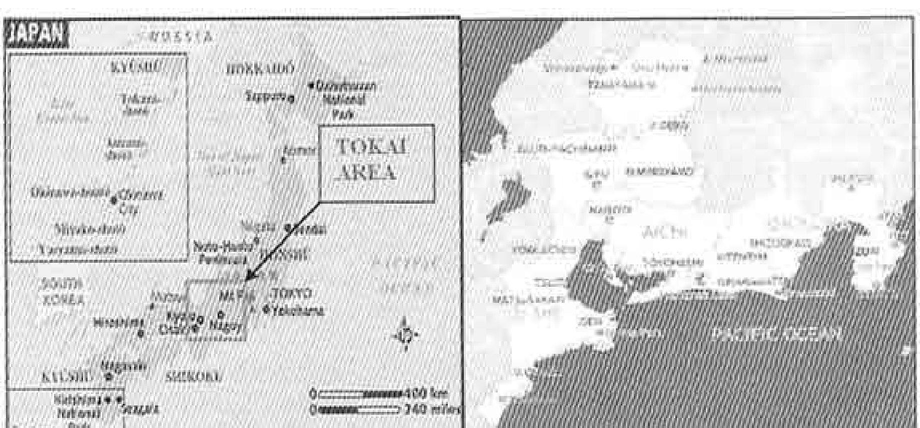


Figure 1.2: a) Map of Japan, b) Map of Tokai area.

(Source: http://www.nikkanren.or.jp/english/tokai.html) observed meteorological database to give an accurate interpretation. The USGS 24-category global land cover data does not represent the actual topography and land use pattern in Tokai area. That is why, a new classification of urban land-cover data was done based on high resolution satellite images to represent the complex land-use pattern in Nagoya. One of the prime objectives of this research was to simulate the urban heat island phenomena and measure its intensity for understanding the urbanization impact on local climate.

2. Methodology

2.1 PSU/NCAR mesoscale model MM5

The Fifth-Generation Penn-State/NCAR mesoscale model MM5 (Dudhia 1993), the latest in series is a numerical meteorological model designed to simulate and predict mesoscale and regional scale atmospheric circulation. The MM5 model is supported by several auxiliary programs i.e. TERRAIN, REGRID, INTERPF and MM5 which are referred to collectively as the MM5 modeling system. Since MM5 is a regional model, it requires an initial condition as well as lateral boundary condition to run. To produce lateral boundary condition for a model run, one needs gridded data to cover the entire time period that the model is integrated.

2.1.1 Dynamic equations and physics options of MM5

The basic equations of MM5 are based on equations from Anthes and Warner (1978), which include pressure, momentum, thermodynamics, advection, and divergence terms. In addition to the dynamic equations that govern the basic variables, schemes and parameterizations for atmospheric radiation, planetary boundary layer, moisture, etc are used to quantify additional grid scale and sub-grid scale meteorological processes.

2.1.2 Land-cover data

A global land use/cover data-base classified according to the 24-category USGS land/cover system is provided with MM5. USGS global elevation data with the resolution 30 sec, USGS 25-category vegetation data of global coverage with the resolution 30 sec for land-use and land-water mask, were used as input to the TERRAIN program of MM5 modeling system. These data contain values of different surface physical parameters such as albedo, emissivity, moisture availability, roughness length and thermal inertia during summer and winter seasons.

2.2 Classification of land-cover

In USGS 24-category land-cover/vegetation dataset the extent of the Nagoya city area is not well represented. A single type of urban land-cover is used in this land-use dataset to represent the entire complex urban area. To make a better representation of complex urban area of Nagoya in the input land-cover dataset for the mesoscale simulation by MM5, a classification system was adopted to classify Landsat thematic image data and thus incorporated into the USGS 24-category land-cover dataset. A supervised classification process was implemented here using simplified maximum likelihood method.

A Geo-Cover Landsat ETM+ data with 30m resolution has been required to completely cover the Aichi area focusing Nagoya city (acquired on December 08, 2000) as the baseline dataset for generation of an initial land cover classification. The study area as shown in Figure 2.1, a subset of 2160x2160 pixels covering same area to the innermost modeling domain (1km grid resolution) selected for TERRAIN program, has been transformed into GeoTIFF format which comprises of urbanized, undisturbed and agricultural regions. These different types of land-uses have distinct texture that can be used as input into classification algorithms. Urban areas typically have significant texture resulting from building and street grids.

A freely available software Multispec (©Purdue Research Foundation) was used in this study to classify the land-cover dataset. Multispec is a processing system for interactively analyzing Earth observational multi-spectral

Figure 2.1: LANDSAT ETM+ image of Nagoya and surrounding area acquired on December 08, 2000 acquired from the Global Land cover facility data center.

(http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp).

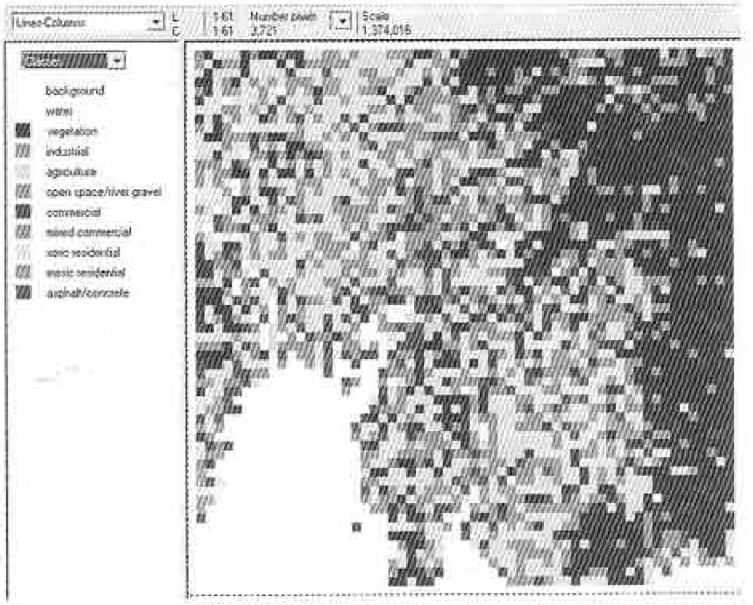


Figure 2.2: New 10-category land use/cover data of Nagoya and surrounding area at 1km resolution by implementing maximum likelihood classification process in Multispec.

image data such as that produced by the Landsat series of Earth satellites.

Figure 2.2 shows the newly classified land use map of Nagoya and surrounding area comprising new 10 land-use classes at 1kmx1km horizontal grid resolution. In the technique for classifying multispectral data, the first step in the analysis is to obtain training samples that are representative of each class of interest. 10 classes of land-use type were selected with 100 training fields (each field is a selected area of each sample class) in the Landsat image by using photo interpretation of Google Earth satellite imagery.

The maximum likelihood classification process was followed with an overall class performance accuracy of 91% in Multispec. Thus a new 10-category land cover classification dataset of 30m resolution was derived from Landsat ETM+ reflectance data. Then the dataset (30m x 30m pixel size) produced by Multispec was transformed in the dataset of 1 kmx1km pixel size (Figure 2.2) by rectification with scale factor 0.027.

The newly classified land-use data was incorporated into MM5 by mapping the 10 categories to the subset of 24 categories in USGS dataset found in the study area. Each MM5 30s grid cell was assigned with highest associated fraction of the land cover class. In addition, two additional urban land use/cover classes were introduced into the revised land cover classification to give three urban categories: urban built-up, urban xeric residential and urban mesic residential which were distinguished by the fraction of vegetation, bare soil and mad made surface. The new urban categories are assigned indices 23 and 24 replacing bare ground Tundra and Snow/Ice in the modified USGS dataset.

Figure 2.3 shows a newly classified land use map of Nagoya and surrounding area at 1kmx1km grid resolution incorporating new 10 categories land use data as shown in Figure 2.2 and standard 24-category USGS land cover dataset. Here Nagoya and surrounding areas are represented as mosaic of different distinct urban zones with urban built-up, xeric residential and mesic residential area. The land-class 1 combines the commercial area, mixed commercial and residential area, industrial area and asphalt/concrete surfaces, mainly concentrated in central Nagoya city around Nagoya castle. The Nagoya sea port and industrial zone along the Pacific Ocean are

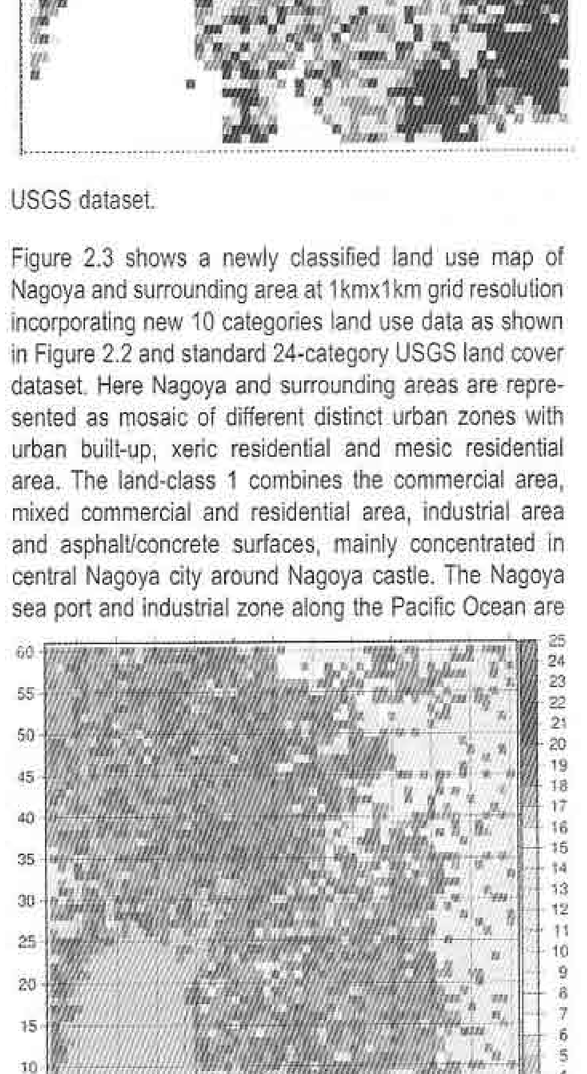


Figure 2.3: Newly modified 24-category land-use types combining standard USGS 24-category and Multispec 10-category land-use types.

represented as urban built-up area. The asphalt made road network and concrete surfaces also constitute the urban built-up area. Some pixels represent the existence of vegetation within Nagoya urban area and also few pixels as water body. The surrounding sub-urban zone made of xeric and mesic residential area is represented by the newly added two urban land-use types 23 and 24 respectively. The wide spread presence of xeric and mesic residential area is shown in the above figure. Irrigated cropland, mixed dry land and even the barren land are effectively shown in the newly classified data set.

2.3 Urban modification in MM5

2.3.1 Parameterization of long wave radiation balance by adding sky view factor

The sky view factor is the fraction of visible sky from a reference point on flat horizontal surface without view obstruction. It is dimensionless parameter ranging from 1 to 0. According to Masson (2000) if width of a road is *w* and the building height is *h*, the sky view factor will be,

$$\Psi_{sky} = \left[(h/w)^{0.5} + 1\right]^{0.5} - h/w$$

A typical distance between two houses (including street and front yard) of 25 m and an average building height of 6m were assumed to determine the sky view factor for a road. A sky-view factor of 0.85 for the xeric and mesic residential land-use categories was obtained by averaging between sky-view factor of road 0.78 and a sky-view factor of 1 for roofs which cover about 30% of an urban

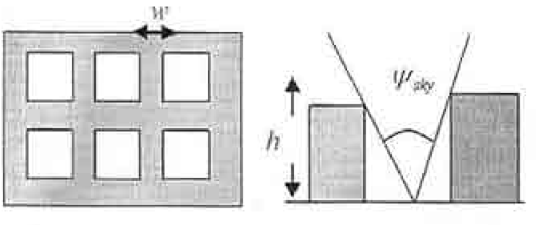


Figure 2.4: a) Typical grid structure of roads and house blocks in city plan (above left); b) Sky view factor.

model grid cell's plan area. As the large variation in road width (30 m to 100 m) and building area complicates the assignment of a single sky-view factor, Ψ_{sky}, we therefore assigned the same value of 0.85 as for the commercial categories (Clarke 2005).

The sky-view factor was introduced to the long wave radiation balance of the urban land cover categories in MM5's slab model (Dudhia 1996) leading to the following equation:

$$R_{long} = \Psi_{sky}\varepsilon_g (L\downarrow - \sigma \cdot T_g)$$

Here $L\downarrow (W \cdot m^{-2})$ is the incoming long wave radiation from the sky, ε_g is the emissivity of the surface, $\sigma (W \cdot m^{-2} \cdot K^4)$ is the Stefan-Boltzmann constant and T_g (K) is the ground temperature.

2.3.2 The addition of anthropogenic heat source term in MRF scheme:

The approach of Sailor and Lu (2004) was adopted here to calculate the anthropogenic heat flux, $Q_a (W \cdot m^{-2})$ as a function of residents and working population densities. The anthropogenic heat flux from traffic for each urban land use class i, $Q^i_{a,v}(h)$ for each day, is calculated according to:

$$Q^i_{a,v}(h) = \rho^i_{pop}(h) \cdot F_t(h) \cdot DVD_c \cdot EV / 3600$$

Where, $\rho^i_{pop}(m^{-2})$ is the average population density, DVD_c is the average daily vehicle distance traveled per person, F_t is the hourly traffic fraction and EV is the energy release per vehicle per meter of travel with values for, DVD_c F_t EV, as in Sailor & Lu (2004). Division by 3600 leads to a conversion of the units of $Q^i_{a,v}$ from $J \cdot hr^{-1} \cdot m^{-2}$ to $W \cdot m^{-2}$

The anthropogenic heat released through electricity consumption, $Q^i_{a,e} (W \cdot m^{-2})$ was calculated by means of monthly totals of electricity consumption by the population of Nagoya city, which was obtained from the official website of Nagoya city authority at http://www.city.nagoya.jp. The data were converted in the daily per capita consumption, $E_c (J \cdot day^{-1})$ and used in the following equation to calculate. $Q^i_{a,e}(h)$

$$Q^i_{a,e}(h) = \rho^i_{pop}(h) \cdot F_e(h) \cdot E_c / 3600$$

Where F_e is the average electricity consumption per day adopted from Sailor and Lu (2004).

The total anthropogenic heat flux Q_a for each urban land use/cover class is then given as the sum of $Q^i_{a,v}$ and $Q^i_{a,e}$. Considering that anthropogenic heat is released directly into the air in the urban canopy, a source term was included in the governing equation of the temperature at the first prognostic level of the MRF scheme as suggested by Taha ('99).

Table 2.1: Physical parameters of urban land use/cover classes as used in modified MM5.

Parameter	Urban built-up	Mesic residential	Xeric residential	Source
Albedo	0.16	0.18	0.18	MOD global albedo dataset
Moisture availability factor	0.005	0.12	0.02	Hope et al.(2003)
Roughness length	0.8	0.5	0.5	Grimmond & Oke (1999)
Volumetric heat capacity	3.0	2.4	2.7	Liu et al.(2004)
Thermal conductivity	3.24	2.4	2.6	Liu et al.(2004)
Sky-view factor	0.85	0.85	0.85	Hope et al.(2003)

2.3.3 Physical parameters of urban land-use classes.

Some physical parameters characterize the land cover categories with respect to their influence on the surface energy budget in MM5. For the urban land use/cover categories these physical parameters were adjusted according to the Table 2.1 based on the fraction of vegetation and manmade surfaces and available data for each land-use type under the given environmental conditions.

2.4 Dataset for initial, boundary conditions and verifications.

The gridded meteorological analyses data as input to REGRID is from the Japan Meteorological Agency (JMA) with 10 km resolution. This AMeDAS gridded regional analyses data provided the initial and boundary conditions for MM5 mesoscale simulation.

For the verification of simulated results with observation, hourly data from Tokai city observation stations (Figure 3.1) was acquired from JMA (http://www.data.kishou.go.jp/).

3. Mesoscale simulations of the urban climate

3.1 Design of numerical experiments

The mesoscale model MM5 version 3.7 was employed for one month simulation starting at Universal Standard Time (UST) from 01 to 30, August, 2003 during summer season. This time was chosen primarily, because during August the maximum near surface temperature prevails at Nagoya city according to the Japan Meteorological Agency (JMA) observation data.

The focal point of modeling domains was centered at Nagoya city with 35.1 degree N and 137.0 degree E. Three computational domains were chosen for nested simulations with 24 vertical layers as details shown in

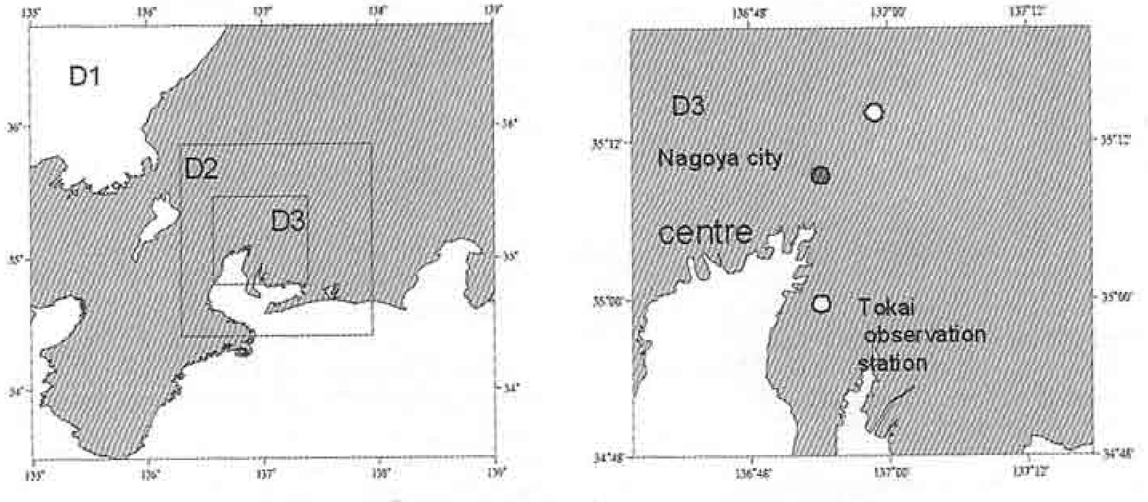


Figure 3.1: a) Modeling domains in MM5, and b) location of Nagoya city centre and observation stations in D3.

Table 3.1: Computational domains and grid arrangements.

Domain	Domain coverage (km x km)	Grid number	Horizontal Grid Size (km)
D1	369 x 369	41 x 41 x 24	9.0 x 9.0
D2	165 x 165	55 x 55 x 24	3.0 x 3.0
D3	61 x 61	61 x 61 x 24	1.0 x 1.0

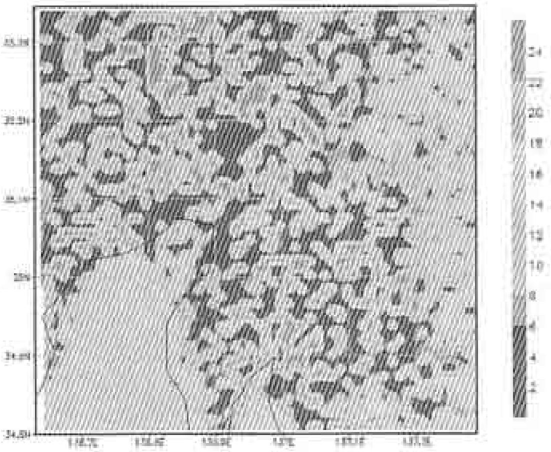


Figure 3.2: Land-use pattern in D3 (resolution: 1km) with newly modified 24-category land-cover.

Figure 3.1 and Table 3.1. The lowest prognostic level was approximately located at 7m above ground level.

Figure 3.2 shows the land-use pattern of Tokai area for domain D3 as generated by MM5's preprocessor TERRAIN for the modified version of 24-category USGS land use/cover-data. The features of the modified land use/cover map area are recognizable as the extended urban built-up area to the south and the relatively large mesic residential area to the west. Simulations were carried out with standard and modified land-cover configurations in order to investigate the model sensitivity of the land-use pattern changes around the urban area.

To investigate the influence of the different land-use/cover scenarios on the simulated 2m air temperatures and surface energy fluxes, three different grid point locations (Table 3.2) in the study area were chosen based on their land-cover characteristics as shown in Figure 3.2; 1) the urban area, which represents urban built up area (type-1) in newly modified 24-category land-use types. This urban type includes central dense commercial built-up area, mixed commercial and residential area, 2) the suburban area, which represents mesic residential area (type-23), and xeric residential areas (type-24) and 3) the rural area, which is mainly made of grass land and mixed forest areas (type-7 & 15) with maximum vegetation and some built forms around.

3.2 Results and discussions

3.2.1 Temperature at 2m

Figures 3.3 and 3.4 show the time series of diurnal temperature at 2m from 01 to 30 August 2003 in urban, suburban and rural area (locations are shown in Figure 3.2), simulated by the standard and modified MM5, respectively. Although the diurnal temperature changes show similar pattern, there are clear differences of near surface temperature among these three locations in both cases. In the first and third weeks, the standard MM5 simulates the high temperature environment (30-34°C), whereas the modified MM5 shows much higher values of temperature (33-38°C). In the middle of month (14 and 15 August 2003), due to high precipitation (45-59 mm) and high wind speed (5-6m/s), the temperature did not rise

Table 3.2: Features of three locations in urban area

	Land-use type in new 24 - category	Latitude	Longitude
Urban	Type-1	35.14 N	136.91 E
Suburban	Type- 23 & 24	35.27 N	136.83 E
Rural	Type -7 & 15	35.14 N	137.14 E

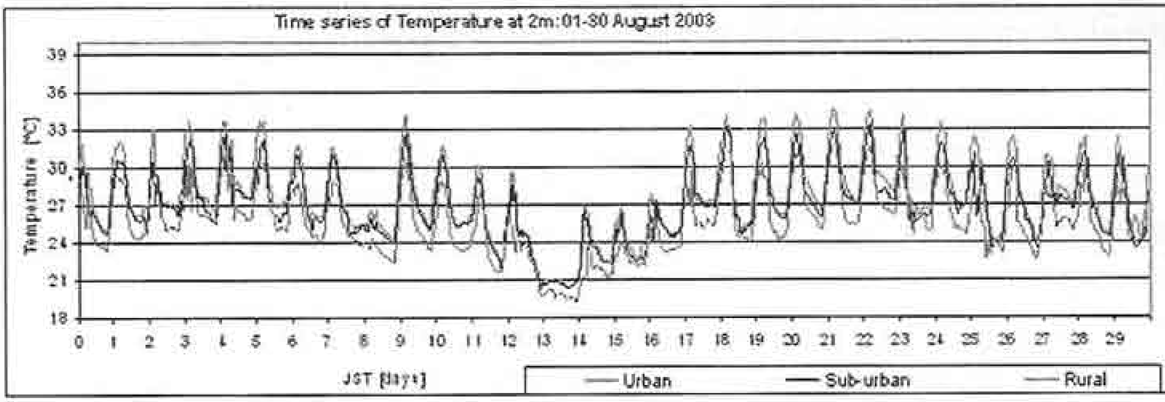


Figure 3.3: Time series of temperature at 2m (01-30 August 2003) by the standard MM5 with USGS land-cover data.

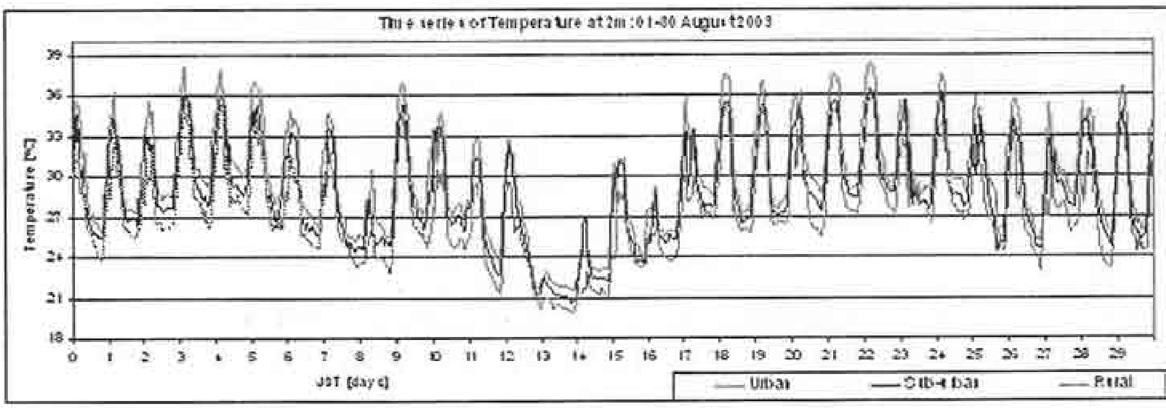


Figure 3.4: Time series of temperature at 2m (01-30 August 2003) by the modified MM5 with newly modified land-cover data.

above 22°C. The results by the modified MM5 indicate consistent increase of temperature with the standard MM5.

In Figure 3.5 the temperature of rural area is lower than that of suburban area and urban area due to the presence of vegetation and wet soil conditions with high moisture availability. The temperature difference between urban and rural area ranges from 3°C to 6°C during the daytime as shown in Figure 3.6, indicating effects of land-cover conversions and additional anthropogenic heat from traffic and electricity consumption on temperature in urban area. An average night-time temperature increase of 2°C in urban area proves the existence of the trapped heat inside building canyons. In rural area, the quick and large radiative heat transfer from vegetated earth surface decreases nocturnal air temperature.

Figure 3.7 shows the distribution of mean temperature at 2m height in the smallest domain D3 from 01 to 07 August 2003 simulated by the modified MM5. In this Figure, the center of Nagoya city concentrates high temperature anomalies (3-6°C) through the whole week, which reveals the signature of heat island phenomena and the highest UHI intensity occurred at 1PM on 03 August 2003, having a temperature difference of 6°C as shown in Figure 3.6. According to the above results, this UHI phenomena happened in Nagoya due to the heat storage in the urban built up surfaces of higher thermal capacity at mid day coinciding with maximum solar radiation. However the night-time temperature difference (1-3°C) is not large enough to develop severe UHI effect in urban area.

3.2.2 Surface energy fluxes

Figure 3.8 shows the time series of latent heat fluxes in urban, suburban and rural area, and Figure 3.9 shows the distribution of mean latent heat fluxes from 01 to 07 August 2003 simulated by the modified MM5. The simulation results indicate that vegetated rural surfaces with more moisture contents have mostly higher latent heat fluxes (up to 440). The urban surfaces are mainly made of asphalt and concrete with characteristics of quick surface runoff and little moisture content for evaporation. Therefore, central Nagoya area shows concentrated lower latent heat fluxes (up to 30) as illustrated in Figure 3.9.

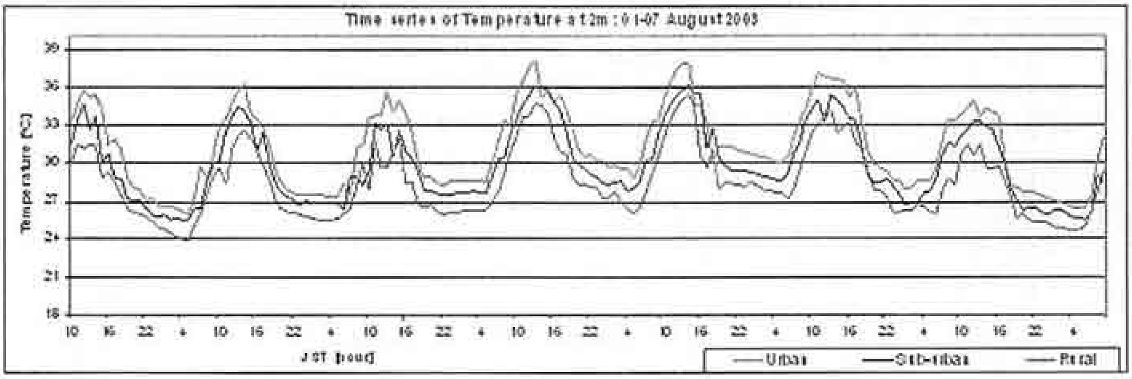


Figure 3.5: Time series of simulated temperature at 2m (01-07 August 2003) by the modified MM5.

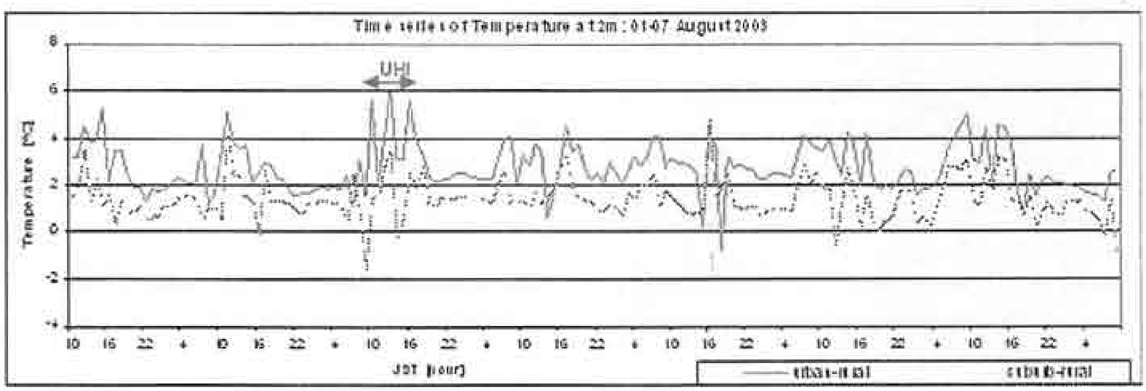


Figure 3.6: Diurnal temperature differences between urban and rural area (01-07 August 2003) by the modified MM5.

Figures 3.10 and Figure 3.11 show that the sensible heat fluxes, are considerably higher (up to 700) in urban area than that of surrounding suburban and rural area. Because urban area is covered with concrete and asphalt surfaces, which have higher volumetric heat capacity (=3.0), and lower albedo (=0.16). On the other hand, rural surfaces mostly covered with vegetation and forests, have lower heat capacity with high moisture availability. The rural surfaces cool atmosphere faster due to high latent heat fluxes. The maximum difference of sensible heat between urban and rural area is 228 on 04 August 2003.

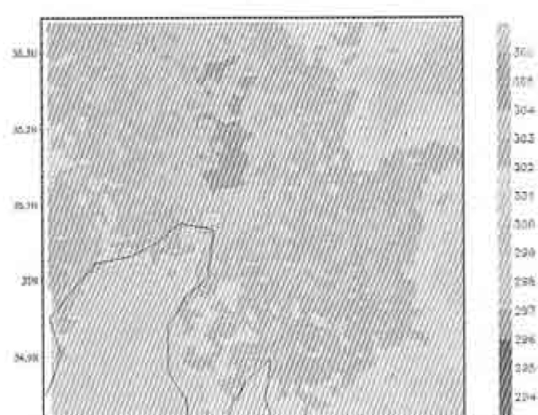
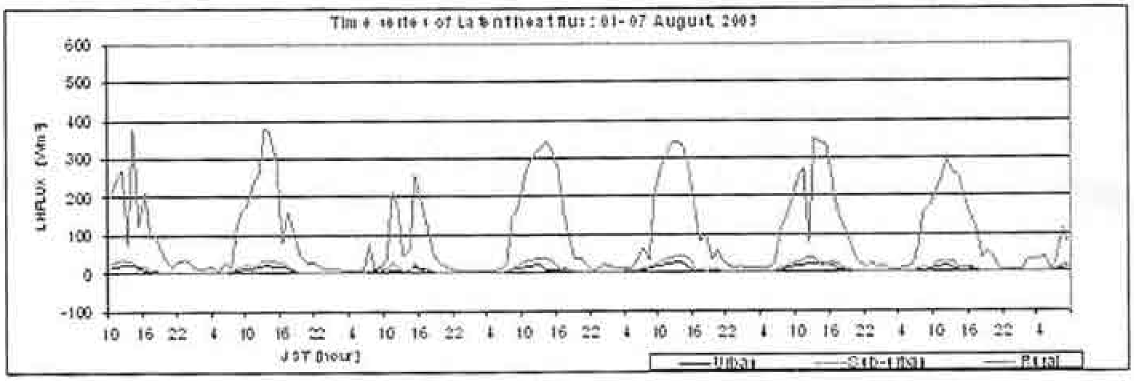


Figure 3.7: Distribution of mean temperature at 2m (D3:1km) on 01-07 August 2003 simulated by the modified MM5 with newly modified land-cover.

According to the above discussion, a significant change in the surface energy fluxes is actualized by land cover changes. Large manmade land-cover in Nagoya city with the presence of few urban parks and water bodies influenced the surface energy fluxes substantially. The heat island phenomenon is closely correlated with lower latent heat fluxes and higher sensible heat fluxes in Nagoya city center as illustrated in the simulated results of Figure 3.9 and 3.11. The urban parameterization of MM5 by modifying heat balance equation has considerable impact on day time energy fluxes in urban, suburban and rural area. Thus it is emphasized that the new land-cover classification with updated physical parameters of urban land-use types substantially changed the energy fluxes in urban area.

Figure 3.8: Time series data of latent heat flux (01-07 August 2003) simulated by the modified MM5.



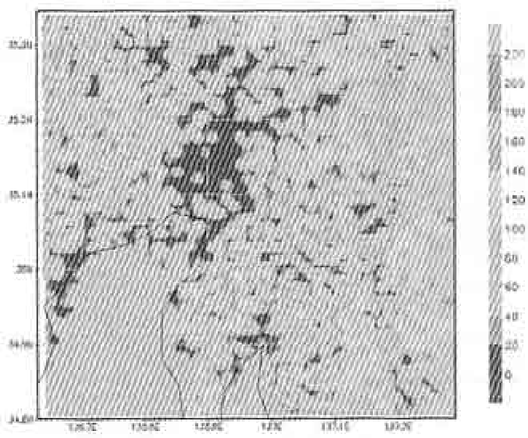


Figure 3.9: Distribution of mean latent heat flux (D3:1km) on 01-07 August 2003 simulated by the modified MM5 with newly modified land-cover.

3.3 Verification of simulation results

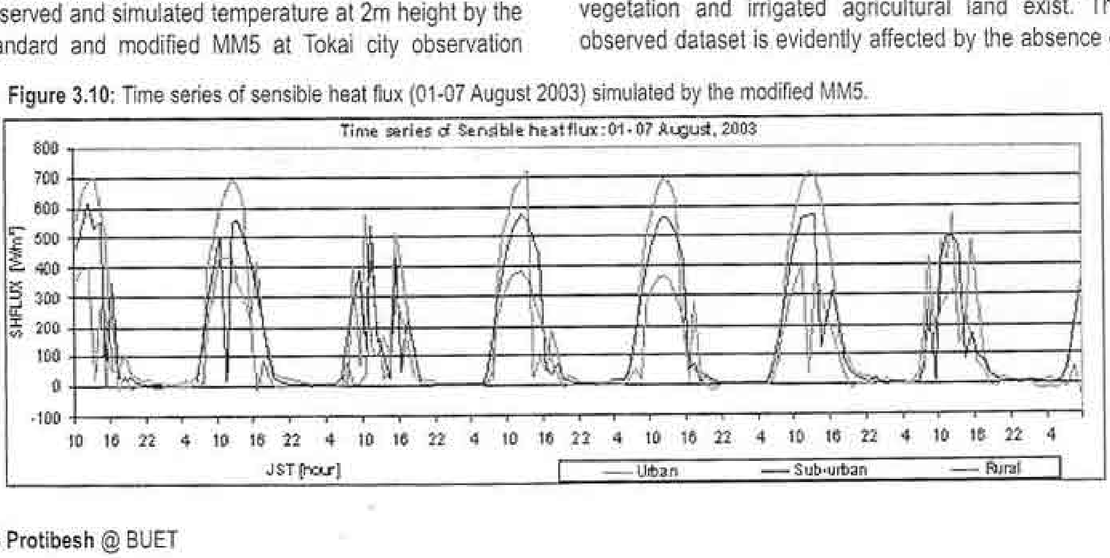
Accuracy of MM5 simulations was evaluated by comparing simulated 2m air temperature, with observation data from Japan Metrological Agency (JMA) observation stations at Tokai city (http://www.data.kishou.go.jp).

Figure 3.12 shows the comparison of time series of observed and simulated temperature at 2m height by the standard and modified MM5 at Tokai city observation point. By modifying the model physics and changing the physical parameters of urban land-use categories (land use type-1, 23 and 24 in Table 3.2), a significant agreement is found in the modified MM5 results (Figure 3.12) at daytime when compared with observed temperature at Tokai city. Comparison of the time series in Figure 3.12 shows the overestimation of night time temperature in case of modified MM5. This overestimation could be related to little radiative cooling as model performance tends to decrease in the day to night transitional period where the rate of decrease in observed temperature exceeds the rate of decrease in simulated temperature. The addition of sky view factor in long wave radiation balance increases the heat storage in urban canyons, decreases the rate of radiative cooling and thus increases night time temperature. The overnight observational temperature typically drops below the modeled temperature by as much as 1°C to 3°C as shown in Figure 3.12.

From the above comparison, it is perceived that the simulations by the modified MM5 has acceptable agreement comparing with observation data at day time as having bias error of -0.102 and correlation coefficient of 0.96.

Generally the locations of the JMA observation stations are outside of the urban neighborhoods, where enough vegetation and irrigated agricultural land exist. The observed dataset is evidently affected by the absence of

Figure 3.10: Time series of sensible heat flux (01-07 August 2003) simulated by the modified MM5.



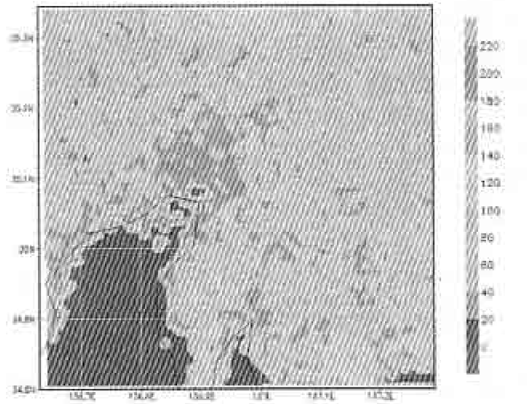


Figure 3.11: Distribution of mean sensible heat flux (D3:1km) on 01-07 August 2003 simulated by the modified MM5 with newly modified land-cover (above right).

different urban factors such as anthropogenic heat, heat storage inside buildings, etc. while measuring the surface air temperatures. Unfortunately atmospheric observation data in Nagoya downtown area was not available for this study; therefore we had to use the freely available JMA data to compare the simulated results.

4. Summary and conclusions

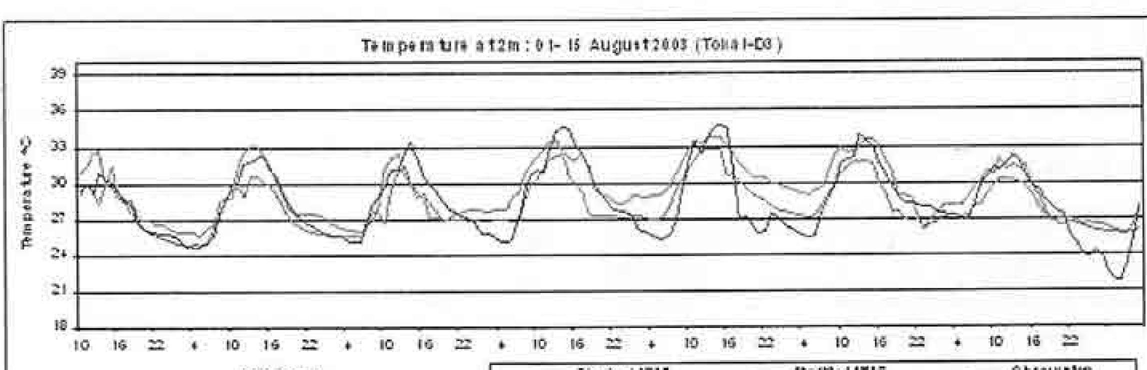
The research process in this study consists of three parts. Firstly, a classical mesoscale meteorological model was modified by including urban factors such as the anthropogenic heating term and sky view factor in the surface energy budget equation. Secondly, a land use category map, related to the several important land surface parameters, was newly classified based on the high resolution satellite images. And thirdly, mesoscale simulation of Nagoya city and surroundings was conducted to evaluate the impact of urban modification using the newly developed model.

In order to perform numerical simulations of Tokai area heat island phenomena, two-way triple nested domains were centered at the Nagoya city center with horizontal resolution 9km/3km/1km. Two-case simulations were performed for one month during the summer in August 2003, using standard MM5 and urban modified MM5. Model performance was validated using surface observation data from Japan Meteorological Agency (JMA). Surface observations were compared with the closest model grid point values in 1km model domain. Results of near surface temperature and surface energy fluxes were analyzed both qualitatively and quantitatively.

Compared with observation data, both models appear good agreement in case of innermost domain with 1km horizontal resolution. In the modified MM5, the 2m air temperature was better simulated at daytime due to addition of anthropogenic heat fluxes and modification of the physical parameters. But the nocturnal near surface temperature differs in comparison with observation. Radiation cooling seems to be a major factor in nocturnal temperature errors that are not well simulated by the modified model. The subgrid scale heterogeneity seems to be the major source of error which is related to improper representation, specification and initialization of surface features including soil moisture, land-use and texture as well as surface energy budget. The observation data provided by JMA is not located in urban areas to maintain representativeness of the data sample. Therefore the observation data does not always reflect the urban phenomenon which differs in some cases. Due to the lack of data for some important parameters, such as energy consumption by vehicles and air-conditioning, and building average height, these values were assumed in reference to other cities derived from published research papers (Sailor 2004 and Clarke 2005). But the qualitative performance was acceptable in terms of comparing temperature and energy fluxes. In future more observations are needed especially within urban area to validate simulated dataset.

The achievement through this study can be summarized to some specific points as follows:

Figure 3.12: Time series of temperature at 2m on 01-07, August 2003 at Tokai observation point.



1) An urban parameterization is implemented in mesoscale model MM5 by adding anthropogenic heat flux in the heat balance equation and sky-view factor in the long wave radiation balance in simple soil model.

2) A land use/cover classification for Tokai area is refined as the newly modified 24-category landcover types by Multispec software using LANDSAT + ETM images. The single urban area of USGS 24-category is classified in urban built up area, xeric residential area and mesic residential area.

3) Values of physical parameters land-use types such as surface albedo, moisture availability, roughness length and thermal heat capacity are adjusted in accordance with local urban phenomena.

4) The results simulated by urban modified MM5, confirm significant improvement in simulated diurnal temperature cycle (average 3.2°C at daytime and 1.7°C at night) and surface energy fluxes (sensible heat flux up to 260 W/m² and latent heat flux up to 600 W/m² at day) in urban area compared to the standard MM5. Although the simulated daytime temperatures show good agreement with observed temperatures, these differ slightly in case of night time temperature (1-3°C), because of improper representation of urban area in observed data.

5) Differences of meteorological fields between urban and rural area suggest the evidence of heat island existence (maximum UHI intensity 6°C) in Nagoya city center. This study also shows that the land-cover changes which result in the decrease of the surface albedo and emissivity, will generate urban heat island phenomena.

Faced with mounting unfavorable circumstances in urban area, the rehabilitation and mitigation of adverse urbanization effects on climate are essential for architecture and urban planning engineering. Therefore future work should involve developing a regional climate map and formulating a design strategy for urban planners and architects in order to mitigate the urban heat island effect and create comfortable and energy efficient urban environment.

End Notes:

1. ***Mesic and Xeric residential area:*** Mesic residential areas are defined by having higher fraction of vegetation, irrigated agricultural land and bare open spaces (type-23), whereas xeric residential areas (type 24) have less vegetation and higher built-up area with irrigated agricultural land and bare open spaces

2. ***MM5 modeling system:*** MM5 modeling system consists of TERRAIN, REGRID, INTERPF and MM5 sub-programs where terrestrial and isobaric meteorological data are horizontally interpolated (programs TERRAIN and REGRID) from a latitude-longitude mesh to a variable high-resolution domain on either a Mercator, Lambert conformal, or polar stereographic projection. Program INTERPF performs the vertical interpolation from pressure levels to the sigma coordinate system of MM5.

References:

Clarke, S.G., Zender J.A, Stefanov W.L., 2005: Urban modifications in a Mesoscale model and effects on near surface variables in and an arid metropolitan region. Journal of Appl. Meteorology, 44, 1281-1297.

Dudhia, J., 1993: A non-hydrostatic version of the Penn State/NCAR mesoscale model: Validation tests and simulation of an Atlantic cyclone and clod front. Mon. Wea. Rev., 121, 1493-1513.

Dudhia, J. 1996: A multilayer soil temperature model for 5. The 6th PSU/NCAR Mesoscale Model Users Workshop, 1996.

Kimura, F. and Takahashi, S., 1991: The effects of land use and anthropogenic heating on the surface temperature in the Tokyo metropolitan area: A numerical experiment, Atmospheric Environment, Vol-25B, No-2, 155-164

Masson, V., 2000: A physically-based scheme for the urban energy budget in atmospheric models. Boundary-Layer Meteorology, 94, 357-397.

Oke, T.R., 1982: The energetic basis of the urban heat island, Quart. J. Roy. Meteor. Soc.,108,1-24.

Sailor, D. J., and L. Lu, 2004: A top-down methodology for developing diurnal and seasonal anthropogenic heating profiles for urban areas. Atmospheric Environment, 38, 2737-2748.

Taha, H., 1999: Modifying a mesoscale meteorological model to better incorporate urban heat storage: A bulk-parameterization approach. J. Appl. Met., 38, 466-473.

Taha, H., 1996: Modeling impacts of large scale albedo changes on ozone air quality in the south coast air basin. Atmospheric Environment. 31, 1667-1676.