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THE IMPACTS OF ANTHROPOGENIC ENERGY AND URBAN CANOPY MODEL ON URBAN ATMOSPHERE

Mauro SUGA[1], Esben ALMKVIST[2], Ryoko ODA[3], Hiroyuki KUSAKA[4] and Manabu KANDA[5]

[1,3] Student Member of JSCE, Doctoral Student, Department of International Development Engineering, Tokyo Institute of Technology (2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, Japan)
[2]Görtborg University, Sweden
[4]Center for Computational Sciences, University of Tsukuba
[5]Member of JSCE, Dr. Eng., Associate Professor, Department of International Development Engineering, Tokyo Institute of Technology (2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, Japan)

This paper reports the effects caused by anthropogenic heat (AH), anthropogenic vapor (AV) and urban canopy model (UCM) on air temperature, wind velocity, mixing vapor and mixed layer height using WRF in August, 2006 at Kanto. Three runs were performed. Run 1 includes AH, AV and UCM. Run 2 includes AH and AV. Run 3 is the WRF original settings. Run 1 can rise monthly average air temperature by 0.75℃ in Tokyo in comparison to Run 3. Under the same circumstances, Run 2 can rise monthly average air temperature by 0.36℃ in comparison to Run 3. Combining AH and AV originates anthropogenic energy (AE). AE and UCM increase mixed layer height, which can reach more than 3 km in Run 1. The enhanced drag of UCM also plays an important role to retard sea breeze penetration into Kanto Region.

Key Words : *meso-scale simulation, anthropogenic heat, Kanto region, urbanization*

1. INTRODUCTION

Notable researches on urban meteorology have shown that urbanization alters several atmospheric and surface processes[1)], which leads to inadvertent climatic changes.

With the advent of computers and its betterment[2)], several numerical mesoscale weather models have been devised. Numerical models can be tuned up mainly by anthropogenic heat (AH) and urban canopy model (UCM) which are expected to improve the bottom layer parameterization. Regarding AH, a pioneer attempt considered it as combustion fuel into a mesoscale model[3)]. The progress of computers allowed the use of more detailed AH data and more accurate results. The following effects can be attributed to AH: (1) causes Urban Heat Island[4)]; (2) can surpass shortwave radiation input in winter, when a mesh registered 1590 Wm^{-2} [5)]; (3) intensifies cloud formation[6)]; (4) increases air temperatures especially at night[7)], assuming a major role at this period[8)]; (5) can augment daily average air temperature by 1℃ in Tokyo[9),10)]; and (6) increases mixing layers height over urban regions[11)].

UCM improves the bottom layer parameterization and the reproduction of nocturnal urban patterns[12)] without excessive computational load. Therefore, notable UCMs using resistance network analogy were deviced[13),14),15)].

However, anthropogenic vapor (AV) has not achieved the same acknowledgement of AH and UCM, which motivated this report to incorporate and assess its effects on mesoscale climate.

The scope of this report is to investigate the impact of AH and AV, which coupled become anthropogenic energy (AE) and UCM on urban atmosphere by using the Weather Research and Forecasting (WRF) modeling system during summer in August of 2006 at Kanto. Three points were chosen as references: Tokyo, Yokohama and Chiba.

2. METHODOLOGY

The simulations were done with 2 nesting. The broader domain (parent domain) covers both axes of 400 km in east-west and south-north directions, as can be seen in **Fig. 1**. It covers central Japan, which may be affected by large sea-breeze circulations[16]. Meanwhile, the smaller domain (child) covers both axes of 100 km in east-west and south-north directions, **Fig. 1** with a finer definition.

The specifications of WRF numerical experiments used in this report are summarized in **Table 1**.

In this study, three runs were performed: Run 1, Run 2 and Run 3. Run 1 incorporates AE and UCM; Run 2 considers only AE: and Run 3 is the WRF default (**Table 2).**

AH and AV were defined based on Geographic Information System (GIS) released by the Tokyo Metropolitan Government (TMG) and Japan District of Heating and Cooling Association (JDHCA). An estimative of energy was obtained by means of combining TMG's statistical data of buildings floor area, and energy consumption statistics of JDHCA (Check Moriwaki et al., 2008 for more details)[17]. Both AH and AV, which form AE, have been incorporated in Runs 1 and 2 and their release height is in the middle of the lowest vertical pressure level. AH reaches 260 W/m^2, which can not be neglected, while the effect of AV, although exists, is small (**Fig. 2**).

AH values by location in August, 2006 are depicted in **Fig. 3**.

Land use parameterization is depicted on **Table 3**.

Although an entire monthly simulation was run, days characterized by rainfall events were discarded. This criterion has 2 conditions: (1) daily rainfall quantity superior to 5 mm and (2) when rainfall occurred for more than 4 hours in a row. It was done by checking Japan Meteorological Agency (JMA) site.

Table 1 Description of WRF settings

Domain	Parent grid lattice	80 x 80 x 50	Grid cell size	5 km
	Child grid lattice			1.25 km
Physics settings				

Physics settings	
Microphysics	Cowry Single-Moment 3-class scheme
Longwave radiation	RRTM scheme
Shortwave radiation	Dudhia scheme
Surface layer	MM5 similarity
Land surface	Noah Land surface scheme
PBL scheme	Mellor-Yamada scheme
Cumulus parameterization	Kain Fritsch scheme

Table 2 Description of simulation conditions

Run	Anthropogenic vapor (AV)	Anthropogenic heat (AH)	Urban canopy model (UCM)
1	On	On	On
2	On	On	Off
3	Off	Off	Off

Table 3 Land use parameterization and UCM parameterization

Land use	Albedo (%)	Moisture availability (%)	Emissivity (% to 9 μm)	Roughness length (cm)	Thermal inertia ($cal.cm^{-2}.k^{-1}.s^{-1/2}$)
Urban and built-up land	15	10	88	80	0.03
Dryland crop and pasture	17	30	98.5	15	0.04
Irrigated cropland pasture	18	50	98.5	10	0.04
Mixed forest	13	30	97	50	0.04
Water	8	100	98	0.01	0.06
Barren	25	2	90	1	0.02

UCM Parameterization

ZR (m)	Z0C (m)	Z0HC (m)	ZDC	ALBR	ALBB	ALBG	SVF
7.5	0.75	0.75	1.5	0.10	0.10	0.10	0.56

R=Building Height; Z0C=Roughness length above canyon for momentum; Z0HC=Roughness length above canyon for heat; ZDC=Zero plane displacement height; ALBR=Surface albedo of roof; ALBB=Surface albedo of building wall; ALBG=Surface albedo of road; SVF=Sky view factor

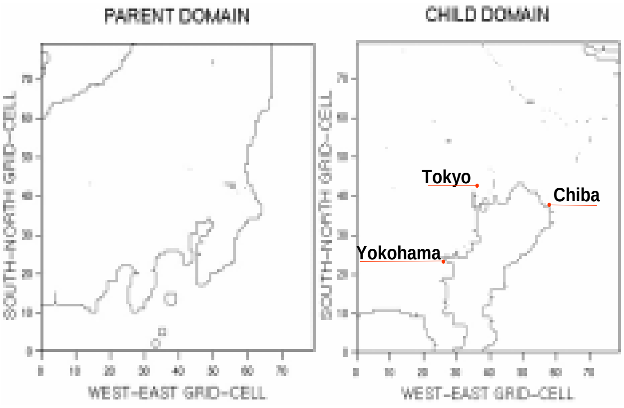

Fig.1 Parent and child domain

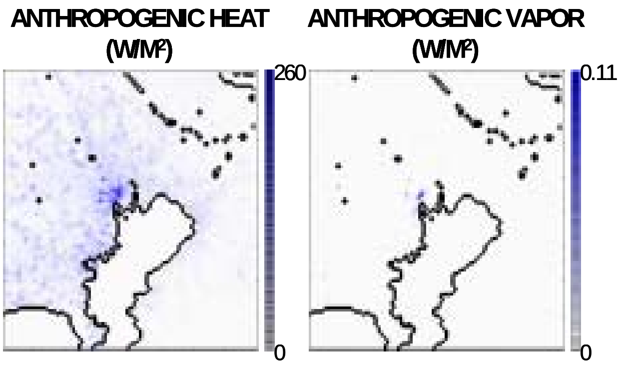

Fig.2 Anthropogenic heat (left) and anthropogenic vapor (right)

3. ENSEMBLE AVERAGE

Ensemble average data was done for all days in August, 2006 excluding rainfall events defined in section 2. WRF output for air temperature and mixing ratio are given at a height of 2 m, whilst for wind velocity the height is 10m. SDP of Tokyo, Yokohama and Chiba were also considered and the height of measurement of air temperature and mixing ratio is 1.5 m at each site. The statistical results can be seen at **Fig. 4** and **Table 4**. An equation to convert the data for a reference height was discarded since the WRF output and SDP data does not differ significantly.

(1) Air Temperature

All cases reproduce diurnal variation of SDP properly. It should be noted that WRF model has been originally well calibrated; therefore it shows good accuracy even in Run 3 (**Fig. 4**).

The overall temperature bias of Run 2 and Run 3 is 0.36°C in Tokyo. A comparison between Run 1 and Run 3 shows greater differences and records 0.75°C in Tokyo (**Table 4**).

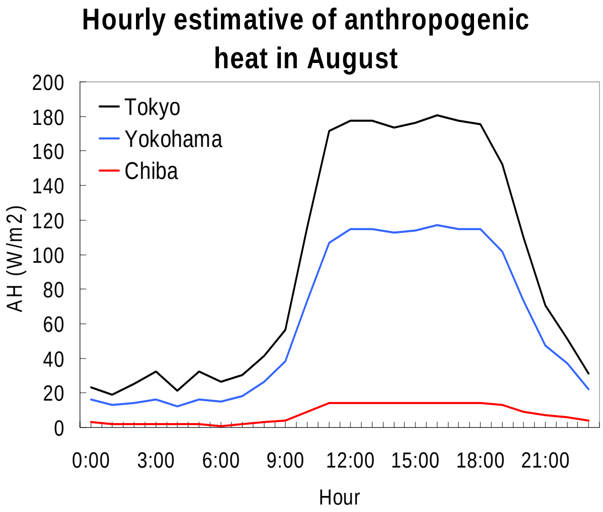

Fig.3 Anthropogenic heat values for Tokyo, Yokohama and Chiba

In the first two hours after sunset (19:00 until 21:00), both Run 2 and Run 1 increase their differences to Run 3. The difference of Run 2 and Run 3 reaches 0.5°C in Tokyo. The difference of Run 1 and Run 3 is stretched to 0.85°C, but a prominent peak of 0.93°C is recorded at 20:00 in Tokyo. It can be explained by 2 reasons:

(1) Without solar radiation, AE values are still high in this period (**Fig. 3**) and the difference of Run 2 and Run 3 is increased

(2) The heat cumulated at UCM is released into the domain, which increases the difference of Run 1 and Run 3 in this period

(2) Wind field

WRF predictions can well reproduce diurnal variation. Run 2 presents the highest average values, followed by Run 1 and Run 3 (**Fig. 4**). It can be explained by the following reasons:

(1) AE provides extra heat, which enhances air temperature and decreases air pressure. It creates some areas of higher gradient pressure, therefore wind velocity is enhanced in Run 2 compared to Run 3

(2) UCM generates extra drag compared to other runs, which slows down wind velocity at Run 1. As a result, it has the lowest values

(3) Mixing Ratio

WRF could not properly reproduce diurnal variation (**Fig. 4**). Run 3 presents the highest average values, followed by Run 2 and Run 1. The extra heat existent in Run 1 and Run 2 enhances vertical circulation which will be discussed in mesoscale analysis section.

Table 4 Ensemble results for August of 2006 and root-mean squared difference (RMSD)

Site	Run 1	Run 2	Run 3	SDP	RMSD Run 1	RMSD Run 2	RMSD Run 3
AUGUST MEAN AIR TEMPERATURE (°C) AND RMSD							
Tokyo	28.70	28.31	27.95	28.23	0.86	0.51	0.66
Yokohama	28.27	27.98	27.73	27.42	0.87	0.59	0.64
Chiba	27.57	27.38	27.21	27.51	0.39	0.23	0.38
AUGUST MEAN WIND VELOCITY (m/s) AND RMSD							
Tokyo	2.77	3.44	3.01	2.72	0.55	1.02	0.71
Yokohama	2.75	3.44	3.22	2.62	0.20	0.85	0.63
Chiba	2.46	3.18	3.04	3.15	0.74	0.31	0.28
AUGUST MEAN MIXING RATIO (g/kg) AND RMSD							
Tokyo	16.16	16.68	16.81	16.16	0.25	0.57	0.71
Yokohama	16.69	16.96	17.08	16.56	0.56	0.64	0.52
Chiba	16.33	16.57	16.66	17.03	0.77	0.56	0.50

HOURLY ENSEMBLE AVERAGE DATA OF WRF AUGUST 2006 PREDICTIONS AND SDP VALUES FOR AIR TEMPERATURE (°C), MIXING RATIO (g/kg) AND WINDVELOCITY (m/s)

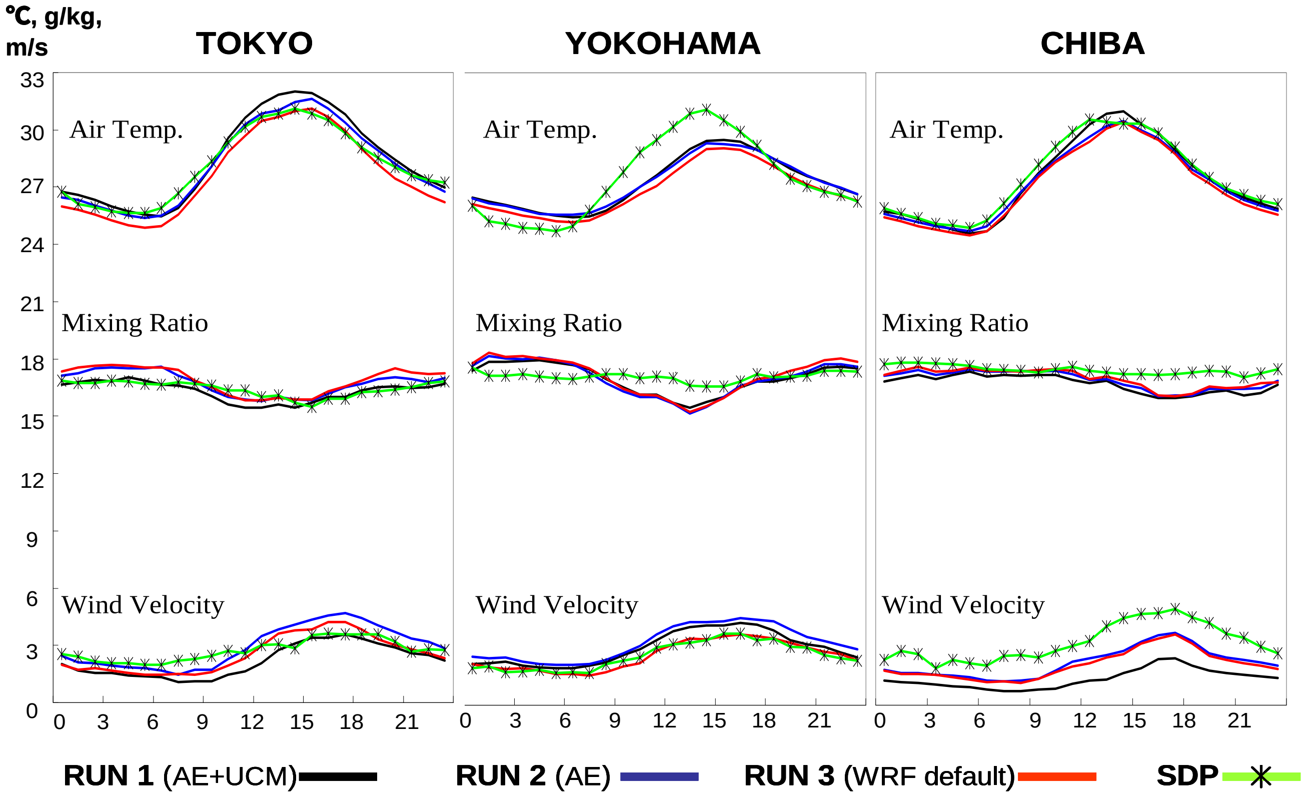

Fig.4 Ensemble average of air temperature, mixing ratio and wind velocity for Tokyo, Yokohama and Chiba

4. MESOSCALE ANALYSIS

The analysis focus on results obtained at August 4th of 2006 at 16:00 in Kanto. This day presented the highest solar radiation input. The results of air temperature, mixed layer height and wind field for different runs can be seen at **Fig. 5**.

(1) Air Temperature

At 16:00, remarkable air temperature differences between Run 1 and Run 3 appear, especially at northwest of Kanto. Meanwhile, the air temperature difference of Run 2 and Run 3 is less evident (**Fig. 5**). It occurs by two reasons. First, AE in Run 2 slightly increases air temperature in Kanto, compared to Run 3. Second, the presence of UCM in Run 1 traps incoming shortwave radiation throughout the day, and added by AE, it results in broad areas of heat (Fig. 5).

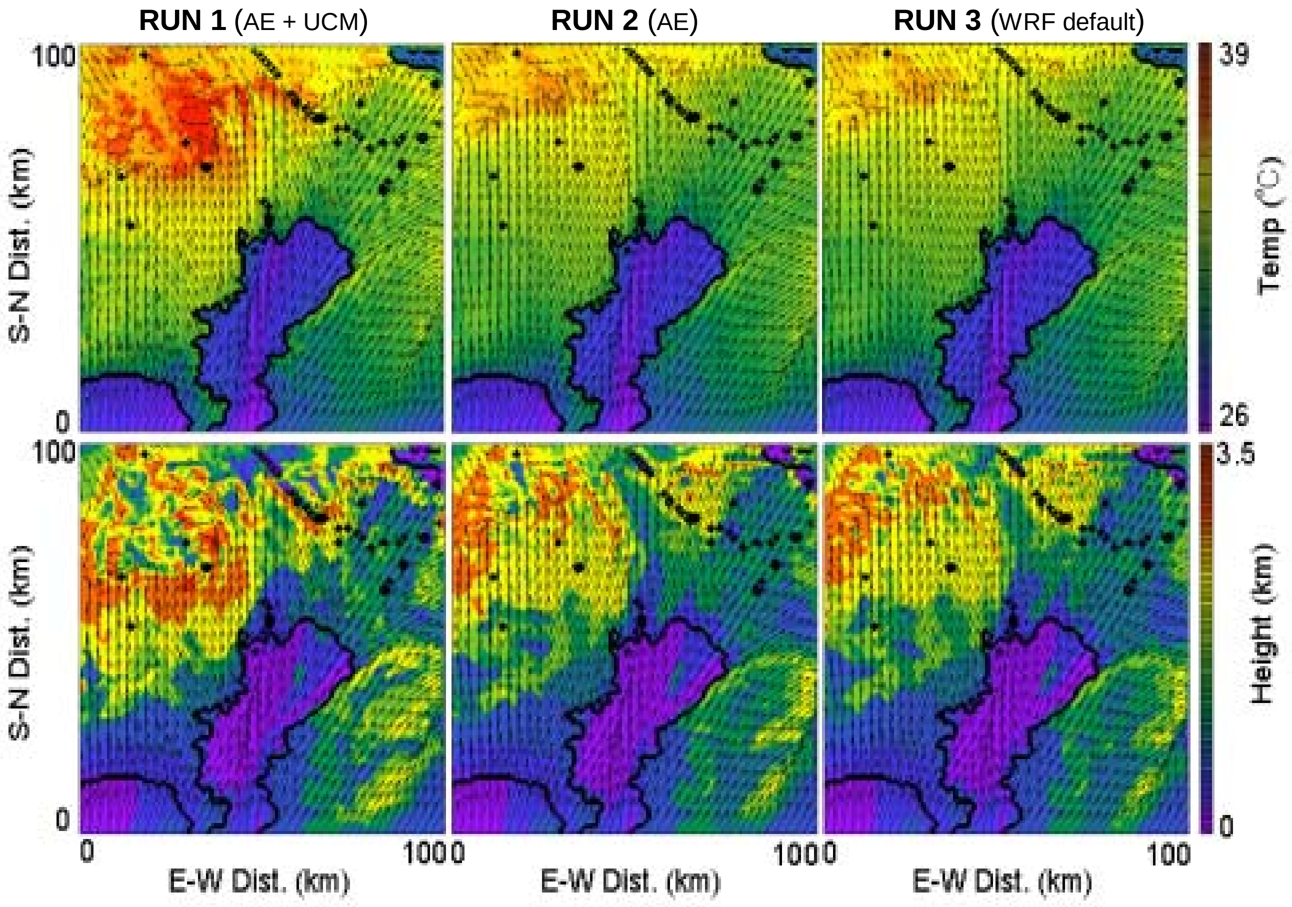

Fig.5 Air temperature (upper row), mixed layer height (lower row) and wind field in Kanto region, Aug. 4th of 2006, at 16:00

In addition to that, Tokyo Bay plays a major role affecting air temperature and wind field simultaneously. Its shape and the low drag of water surface boosts sea breeze and drives it to northeast of Kanto. So forth, sea breeze advection is enhanced and is very effective to cool down the northeast area of Kanto in all runs.

(2) Wind field

Run 1 shows a significant difference of sea breeze penetration in comparison with Run 3. Sea breeze penetration in Run 2 is slightly hampered compared with Run 3. It can be explained by AE and UCM.

AE slightly boosts horizontal wind in Kanto, however the sea breeze penetration in Run 2 does not differ so much from Run 3.

UCM in Run 1, by means of drag effects strongly retards sea breeze penetration in Run 1 (**Fig. 5**). In addition to that, the warmer areas of Run 1 show changes of wind direction in comparison with other runs and wind velocity is slowed down.

(3) Mixed Layer Height

A glance at **Fig. 5** shows a general trend for all runs. Mixed layer heights topping more than 2 km are found at northwest of Kanto while at northeast mixed layer height does not develop in the same extent. It is explained by Tokyo Bay, which boosts and drives sea breeze to northeast of Kanto, cooling down the area and preventing the formation of mixed layer heights as high as in northwest of Kanto.

At northwest, Run 1 presents broad areas of mixed layer height of 3 km, and some peaks of 3.3 km. Run 2 has mixed layer heights lower than Run 1. Run 3 has the lowest mixed layer heights. The position of areas of higher mixed layer heights at Run 1 (in orange in **Fig. 5**) is closer to the ocean, while for Runs 2 and 3 these areas are located further in land. It means UCM in Run 1 greatly enhances the vertical circulation and drastically retards sea breeze penetration, while AE exerts a slight influence.

Therefore, water vapor molecules close to the ground level do not differ so much in Run 2 and Run 3, while Run 1 clearly presents the lowest values of mixing ratio. The higher is the mixed layer height at a location, the lower is the mixing ratio close to the ground. AE and UCM trigger a mechanism enhancing vertical circulation, which uplifts water molecules to higher heights. Close to ground level mixing ratio values are lower, especially for Run 1.

5. CONCLUSIONS

The impact of anthropogenic energy (AE), which is the sum of anthropogenic heat (AH) and anthropogenic vapor (AV), coupled to UCM on urban atmosphere was investigated by using numerical modeling system WRF.

In this study, the following remarkable points were obtained:

(1) WRF runs can well reproduce diurnal variation of air temperature and wind velocity.
(2) WRF runs were not able to well reproduce diurnal variation of mixing ratio.
(3) AE in Run 2 can rise August monthly ensemble air temperature by 0.36℃ in Tokyo.
(4) AE and UCM in Run 1 can rise August monthly ensemble air temperature by 0.75℃ in Tokyo
(5) Tokyo Bay plays a central role by means of driving and boosting sea breeze, which cools down the northeast area of Kanto and inhibits mixing layer height as high as in northwest.
(6) Both Run 1 and Run 2 enhance mixed layer height formation. It increases air temperature, augments buoyancy, and enhances vertical circulation system, therefore uplifting water molecules to higher heights, especially in Run 1 due to the higher drag.
(7) Sea breeze interacts with mixed layer height, enhancing vertical circulation height in the front at northwest of Kanto. In Run 1, sea breeze is strongly retarded and advection effects are greatly decreased. It is one of the reasons of why mixing ratio values at 2 m are lower in Run 1 than Run 3.

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