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TEMPERATURE RISE IN A TROPICAL SOUTH-EASTERN ASIAN CITY, JOHOR BAHRU, MALAYSIA, CAUSED BY EXTENDED URBANIZATION: NUMERICAL ANALYSIS FOR 1970, 2000, AND 2020 BASED ON LAND-USE DISTRIBUTION

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Abstract
Annual average of observed temperature at Senai (International Airport of Johor Bahru, JB) in the suburbs of JB, Malaysia has been increased by about 1.1°C for the last three decades. In the present study, this phenomenon was investigated numerically by using PSU/NCAR meso-scale model (MM5) with land-use of 1970 and 2000 so that possible contribution of extended urbanization of JB to the temperature rise was evaluated. Additionally, possible temperature increase in 2020 was also calculated based on a city planning of JB. Obtained results showed: (1) estimated increase of daily-and-area-averaged temperature was 0.64°C in the suburbs and 0.87°C in the city center of JB for the thirty years from 1970 to 2000; (2) further increase of 0.89°C was predicted in the city center from 2000 to 2020 with a town planning of Johor Bahru; (3) that urbanization in Singapore may significantly affect the temperature in JB was also suggested.

Key words: heat island, tropical city, south-east Asia, Johor Bahru, land-use planning

1. INTRODUCTION
Rapidly expanded urbanization in the last four or five decades now causes unpleasant temperature rise in the summertime in Japanese mega cities such as Tokyo, Osaka, and Nagoya. Change of land surface from forest, rice paddy, etc. to buildings, and paved roads mainly contributes to the increase of temperature, and enhanced energy use in urbanized area may be additional reason for it. Such an example for Nagoya area was investigated in Kitada et al. (1998) etc. Temperature rise caused by urbanization demands further energy consumption for cooling (e.g., Ashie, et al., 2001), and thus likely leads to increased emission of green house gases. We may avoid this additional energy consumption by careful urban planning such as land use planning, planning for spatial distribution of buildings with controlled heights, use of appropriate building material, and surface color, etc. The same thing could occur even in tropical area. In this study, for a step to an "energy saving city" of Johor Bahru (JB), we have analyzed temperature change in JB during the last three decades, and evaluated effect of the extended urbanization in JB on the temperature increase by using meso-scale meteorological model (MM5). We also estimated possible temperature rise in JB at the year 2020 based on a future land use planning (Ho, 2002).

2. CHANGES OF TEMPERATURE, POPULATION, AND LAND USE IN JOHOR BAHRU AREA FROM 1974 TO 2000

2.1. Temperature
Johor Bahru (JB) is the second largest city in Malaysia, and is located at 1º29'N and 103º44'E and at the southern most chip of Malay Peninsula. JB has expanded rapidly in its population, urbanized area, and economy for the last three decades. Economic development of Singapore also has stimulated the development of JB. Fig. 1 shows locations of Johor Bahru, Singapore, etc.

At the Johor Bahru International Airport in Senai (i.e., SE in Fig. 1), meteorological data of temperature, humidity, wind, solar radiation, and rainfall intensity have been measured since 1974 (Perkhidmatan Kajicuaca Malaysia, 2000). Based on the data, we have examined change of temperature for about 25 years. Fig. 2 shows trends of daily-maximum, -average, and -minimum temperatures at Senai. All of these suggest their increases of about 1.1ºC for 27 years from 1974 to 2000. (Meanwhile, annual precipitation during 20 years from 1981 to 2000 did not show simple monotonic trend, and it had a value ranging from 1860 to 2890 mm/yr.) Monthly-averaged temperature at SE (in Greater JB) shows its seasonal variation: the highest temperature during April to June, the second highest in October, and the lowest in December and January.

Fig. 1. Johor Bahru and Singapore. JB: Johor Bahru, and SE: Senai. SE is a part of the "Greater Johor Bahru". Meteorological factors such as temperature, humidity, wind etc. are continuously monitored at SE.

Increases of temperatures shown in Fig. 2 may include effects by global warming. According to the IPCC report (IPCC, 2001), temperature rise attributable to the global warming is 0.17 ºC (0.24ºC in Northern Hemisphere and 0.11ºC in Southern Hemisphere) for 25 years from 1976 to 2000. If we assume this 0.17ºC as the increase of temperature at SE (Greater JB) by global scale warming, a difference of 0.93ºC (=1.1-0.17) could be due to urbanization in the region. Thus we have tried to estimate how much the temperature in JB has been raised by the urbanization. Furthermore we have tried to predict temperature rise based on a future land use planning in the Greater JB in 2020.

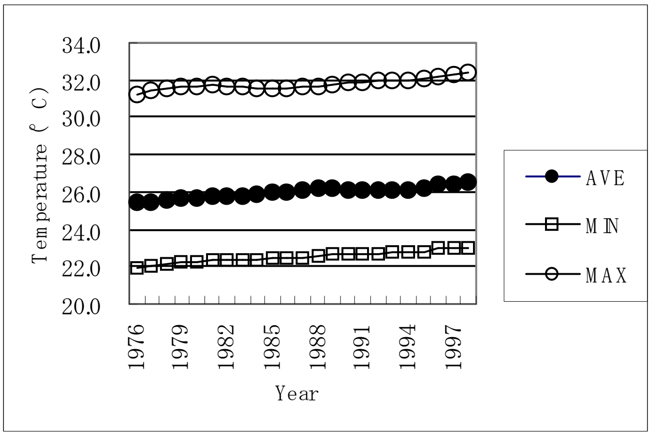


Fig. 2. Five-year running mean of annually-averaged temperatures at Senai (SE in Fig. 1): daily maximum (○), daily average (●), and daily minimum (□).

2.2. Population and land use

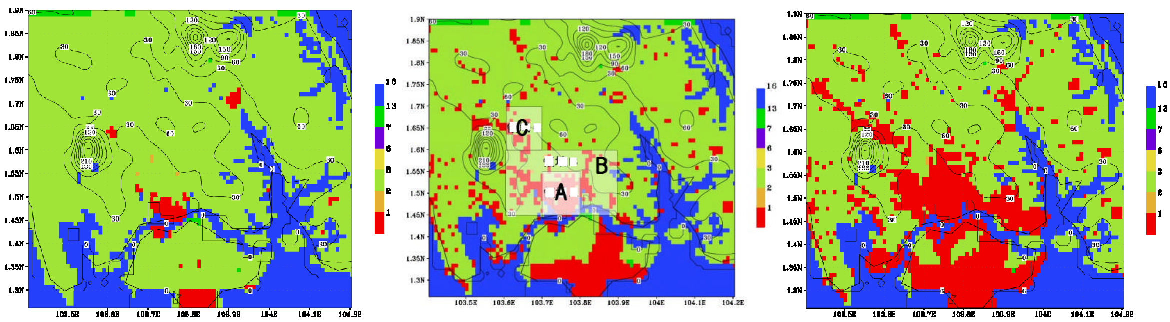
As shown in Table 1, population of Johor Bahru has rapidly increased, and is expected to further increase in the future. For example, the population in JB was increased by about 1.5 times from 440,000 in 1991 to 680,000 in 2003. Moreover, it is expected the population of the metropolitan Johor Bahru (the greater JB) may increase by a factor of 3.8 for 25 years: that is, 1 million in 1996 to 3.8 million in 2020.

With this increase of population, land use of the state of Johor was largely changed from forest and irrigated crop field to urban area. Enhancement of the change is further predicted for the next 20 years. Figs. 3a, b, and c illustrate land use maps for 1970, 2000, and 2020. These maps were prepared based on the study by Ho (2002); these land use maps were used for meteorological simulations using MM5.

Table 1. Population in Johor Bahru: past, present, and future.

Year	1991	1996	2000	2003	2005	2020
Johor Bahru	440*		630	680		
Metropolitan Johor Bahru#		1000			1400	3800

- Unit of the population is one thousand. # The "Metropolitan Johor Bahru (the Greater JB)" covers Johor Bahru and other communities which form the metropolitan area.



(a) 1970. (b) 2000. (c) 2020.

Fig. 3. Land use map for Johor Bahru area: (a) 1970, (b) 2000, and (c) 2020. These were prepared based on detailed lad use descriptions by Ho (2002). Land use type indicates: "red" for urban area, "green" for evergreen broad leaf, and "blue" for water bodies. These maps represent Domain 2 in MM5 simulations (see subsection 2.3.). In (b), Sub-regions A, B, and C are defined for temperature analysis: "A" the old downtown of Johor Bahru (JB), "B" the extended city area of JB, and C the northern suburbs of JB. For each area of A, B, and C, relation of increased urbanized-area ratio with sub-region-averaged temperature rise will be quantitatively evaluated in subsection **3.2**.

2.3. MM5 simulation and surface parameters

In MM5 (Grell et al., 1995, and Dudhia et a., 1999) simulations, two domains were defined: Domain 1 covered the area of 150 km x 150 km with a horizontal grid size of 3 km, and Domain 2 (see Fig. 3 for the area) with the area of 90 km x 73 km and a grid size of 1 km was nested in Domain 1. To describe a larger-scale meteorology during the simulations, ECMWF outputs were used: they were geo-potential height, winds, temperature, and humidity at 0.5ºx0.5º grid with 6 h interval for 3 days from 00GMT 4Mar to 00GMT 7Mar2001.

The simulations were performed using a non-hydrostatic version with the parameterizations: "MRF PBL" for planetary boundary layer, "Cloud-radiation" scheme for radiation process, "Simple ice (Dudhia)" for cloud microphysical process, and "Five-layer soil model" with "Surface energy equation". The surface energy equation is given by:

$$C_g \frac{dT_g}{dt} = R_n - H_m - H_s - L_v E_s \qquad (1)$$

where T_g *is the surface temperature*, R_n *is the net radiation flux*, H_m *is the heat flow into the substrate*, H_s is the sensible heat flux into the atmosphere, L_v is the latent heat of vaporization, E_s is the surface moisture flux, and C_g is the thermal capacity of the slab per unit area. $C_g = 3.293 \times 10^6 \chi, \quad \chi = (\lambda C_s)^{1/2}$ (2)

Parameter χ is the "thermal inertia" and is specified as a function of land-use characteristic. Thermal characteristic of each land-use type is taken into the calculation through the terms of $R_n, H_m, H_s, E_s,$ *and* χ, in which the parameters in Table 2 determining thermal characteristic are included (see Grell et al., 1995).

Table 2. Surface parameters related to thermal characteristic in MM5 simulation.

Vegetation Description	Albedo (%)		Moisture Availability (%)		Emissivity (% at 9 µm)		Roughness Length (cm)		Thermal Inertia. (cal cm^{-2}K^{-1}s$^{-1/2}$)	
	S$	W$	S	W	S	W	S	W	S	W
Urban	18	18	10	10	88	88	50	50	0.03	0.03
Evergreen Broadleaf	12	12	50	50	95	95	50	50	0.05	0.05
Grassland	19	23	15	30	92	92	0.12	0.10	0.03	0.04
Water Bodies	8	8	100	100	98	98	0.01	0.01	0.06	0.06

$ "S" and "W" stand for warm and cold season, respectively.

2.4. Simulation cases

To study effects of urbanization on temperature distribution in "Domain 2" (see Fig. 3), five scenarios were calculated (see Table 3). Case 1, 2, and 3 were to see the effects of land use distribution in 1970, 2000, and 2020 (as shown in Figs. 3a b, c), respectively. Case 4 and 5 were designed specifically to look at the effect of urbanization of Singapore on temperature in Domain 2.

Table 3. Simulation cases.

	Land Use Distribution (Domain 2)#	Land Use in Singapore
Case 1	1970 (Fig. 3a)	As exactly in Fig. 3a.
Case 2 (Base)	2000 (Fig. 3b)	As exactly in Fig. 3b.
Case 3	2020 (Fig. 3c)	As exactly in Fig. 3c.
Case 4	2000 (Fig. 3b)	"Evergreen broadleaf" is assumed.
Case 5	2020 (Fig. 3c)	"Evergreen broadleaf" is assumed.

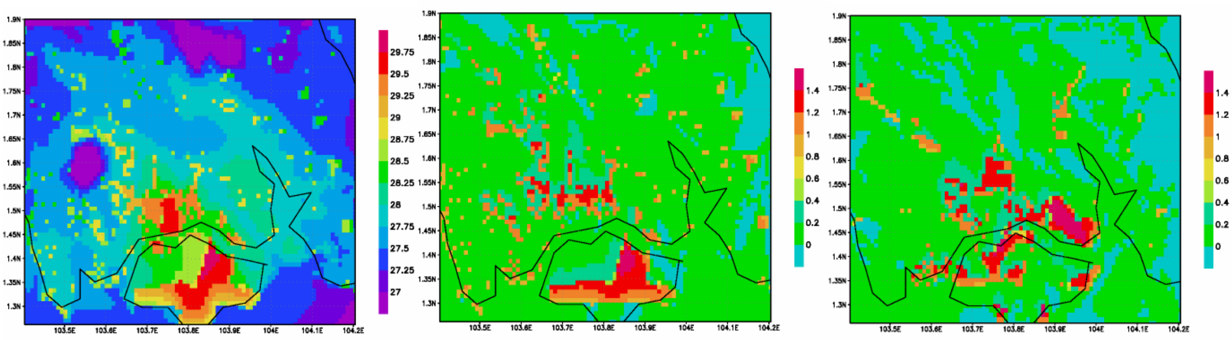
Urban area in the state of Johor (i.e., the area in Figs. 3a, b, c less Singapore) was increased by 6.5 times from 1970 to 2000, and is expected to be increased by 1.6 times from 2000 to 2020.

3. RESULTS AND DISCUSSION

Each simulation in Table 3 included 3-day calculation from 00GMT on 4 March to 00GMT on 7 March 2001. Larger scale meteorological field was given every 6 hours by ECMWF analysis data with resolution of 0.5ºx0.5º. We chose "March" for simulation since it is the beginning of hot season from March to June and its average temperature seems to be close to the annual mean temperature (Perkhidmatan Kajicuaca Malaysia, 2000), though we do not, of course, intend to do exact reproduction of the temperature rise in Fig. 2.

3.1. Temperature distribution affected by the change of land use

Fig. 4a shows one-day averaged temperature at 2 m on sunny day in 2000 (Case 2 in Table 3 and the land use in Fig. 3b); higher temperatures are found over JB and Singapore; temperature in the downtown JB is by 1-1.5ºC higher than rural area. Fig. 4b shows temperature increase/decrease due to the change in land use distribution for 30 years from 1970 (land-use in Fig. 3a) to 2000 (land-use in Fig. 3b). Increasing temperature in newly urbanized area in JB and Singapore is demonstrated with its maximum level exceeding 1.4 ºC. Estimated increase of the one-day averaged temperature from '1970' to '2000' was about 0.6ºC at Senai, which is smaller than the observation-derived value of about 0.9ºC. In '2020' (Fig. 4c), significant temperature increase is suggested in the area on the east and the nort of JB, where further urbanization/industrialization is planned (see Fig. 3c).



(a) One-day-averaged temperature in 2000 (Case 2).

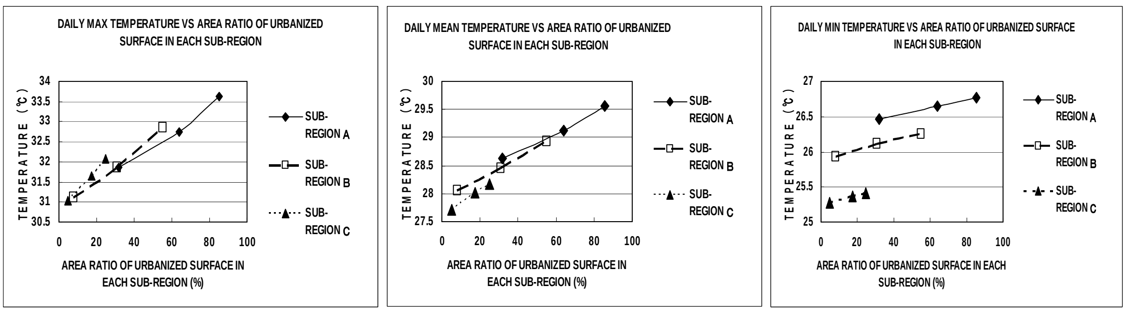
(b) Increase of one-day-averaged temperature caused by land-use change from 1970 (Case1) to 2000 (Case 2).

(c) Same as (b) but for 2000 and 2020.

Fig. 4. Calculated temperatures (ºC) at 2 m in Domain 2: (a) one-day averaged temperature on sunny day in March in Case 2 (Base: land use in 2000, Fig. 3b), (b) temperature difference: Case2 (2000)-Case 1(1970), and (c) the same but for Case 3 (2020) – Case 2 (2000). The figures are all based on one day averaged values on sunny day.

3.2. Quantitative analysis on the relation between urbanization ratio and temperature rise

To quantitatively investigate effect of ‘area ratio of urbanized surface’ on temperature, three sub-regions were defined (see Fig. 3b): the old downtown of JB (“A” in Fig. 3b), developed city area of JB (“B” in Fig. 3b), and the northern suburbs of JB including Senai (“C” in Fig. 3b). In Figs. 5a,b,c, daily-maximum, -mean, and -min temperatures which were averaged over each sub-region are plotted against area ratios of urbanized surface in the corresponding sub-regions. Fig. 5a suggests that urbanization contributes mainly to increase of daily maximum temperature, while daily minimum temperature, which usually occurs at the end of night, is less affected by it. From Figs. 5a,b, increase of temperature for 30 years from 1970 to 2000 can be 0.4-0.6 ºC and 0.5-0.9 ºC in sub-regions ‘C’ (in cluding Senai) and ‘A’, respectively.



(a) (b) (c)

Fig. 5. Temperatures averaged over each sub-region vs. area ratio of urbanized surface in each sub-region; the temperatures were calculated in Case 1 (land use for 1970), 2 (2000), and 3 (2020): (a) daily-maximum-, (b) daily-mean-, and (c) daily-min-temperatures. In the figures urbanized area ratio of “low”, “medium”, and “high” in each sub-region corresponds to the year “1970”, “2000”, and “2020”, respectively. See Fig. 3b for locations of the sub-regions A, B, and C.

4. SUMMARY

In this study, thermal environment in Johor Bahru (JB) was investigated for 1970, 2000, and 2020 in terms of influence of expanded urbanization in the Greater Johor Bahru and also in Singapore. Quantitative evaluation on the influence was performed by the numerical simulation of a meso-scale meteorological model, MM5, with land use distributions for 1970, 2000, and 2020.

References

Ashie, Y., et al., 2001. *J. Global Environ. Eng.*, JSCE, **7**, 101-117. Grell, G.A., et al., 1995. NCAR/TN-398+STR, NCAR. IPCC, 2001. *Climate Change 2001: The Scientific Basis*, Cambridge Univ. Press, 115.
Ho, C.S., 2002. Land use maps of Johor Bahru area for 1970, 2000, and 2020, *Built Env., UTM*.
Kitada, T., Okamura, K., Tanaka, S., 1998. *J. Appl. Meteor.*, **37**, 1026-1046.
Perkhidmatan Kajicuaca Malaysia, 2000. *Meteorological Records at Senai* .