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INFLUENCE OF SEA SURFACE TEMPERATURE ON COASTAL URBAN AREA - CASE STUDY IN OSAKA BAY, JAPAN -

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This study simulates atmospheric environments at Osaka bay area of Japan using the numerical weather prediction with highly accurate sea surface temperature (SST) data from the satellite. A series of numerical experiments for understanding urban heat island at Osaka bay area is conducted considering latest information of land use classifications, SST and an urban canopy model. The accurate daily information of SST at Osaka bay improves the daily temperature at the center of Osaka city. In addition, the one degree SST increase has impact to 0.6 degree increase of maximum temperature at the center of Osaka city.

1. Introduction

Temperature of urban areas has been increased due to urbanization, so-called the heat island phenomenon, and it becomes significant the last a few decades. The average temperature rises in Osaka and Tokyo are known to be faster than twice of global average temperature rise rate associated with the global warming [1]. There are several reasons of the heat island phenomenon such as the land use change, the effect of the building and the increase in urban heat release from air conditioning equipment [2]. The studies of the heat island phenomenon have been done since the late 1980s. It is verified by observations and the accumulation of numerical data [3]. The raised temperature due to heat island phenomenon is presumed 2 degrees by changes of land use in metropolitan area

in Japan, 2 degrees by the effect of building, 0.5 degree by increase of anthropogenic heat release [4].

The geometry of Osaka is located the narrow plains around Osaka Bay. Osaka plain has a complex terrain consisting of surrounding mountains and several rivers. Fujibe reported the daily changing direction of the sea breeze flow and the related heat exchange on the land surface [5]. Mizuma showed that the diurnal sea breeze from Osaka Bay changes over time to Kii Channel in the southern Osaka Bay and that the sea breeze continues until late afternoon in the coastal area of Osaka Bay by analyzing observed data of AMeDAS [6].

Regarding the heat island influences, Yamamoto pointed out that reaching the sea breeze front from the Osaka bay to the inland became about one hour later and the total sea breeze duration is shorter comparing from 1972-1975 to 1991-1995 in Osaka plain [7]. There are some examples of numerical study focused on Osaka. Narumi *et al.* reported a study of the anthropogenic heat impact, and they showed temperature rise and the change in the wind distribution due to increase anthropogenic heat [8]. Meanwhile, it is important to know the heat transfer relationship between the upper ocean and coastal urban areas such as the Osaka or Tokyo bay areas in Japan. Because it relates diurnal sea and land breezes and ocean roles is not only a buffer to the heat but also the exchange of momentum between sea surface and winds. Previous numerical studies reproduce an overview of urban-specific weather, although it is hard to say that it accurately projects urban weather located in the coastal area quantitatively. In the past a few years, numerical simulations have been carried out considering SST change targeted around Tokyo [9], but the case study focused on Osaka is not considered despite the phenomenon of the strong regional characteristics. In addition, Osaka urban climate is more sensitive than Tokyo due to the ratio of land-sea area. The importance of accurate assessment of urban climate around the coastal mega cities becomes significantly demanding.

In this study, the influence of coastal sea surface temperature on coastal urban area is simulated by using a meteorological model as a case study of Osaka Bay, Japan. Additionally the pseudo experiments of sea surface temperature increasing are evaluated as global warming impact to coastal urban area.

2. Model and Input Data

2.1. *Numerical Model*

Weather Research and Forecast (WRF) as the numerical model for urban weather projection is used[10]. The WRF model is a non-hydrostatic, compressible model with a mass coordinate system. It was designed as a numerical weather prediction model both research and operation. WRF has suitable to try the sensitivity of various physical processes to temperature near

the urban area. In this study, single-layer urban canopy model (SLUCM) developed by Kusaka and Kimura[11] is used. SLUCM is assumed homogeneous buildings, and they consider radiation and reflection of the heat in the canopy. For example, short and long wave radiation absorbed into ground is applied rate of building wall and roof like sky factor, and long wave radiation from ground is calculated. Although this model is single-layer model, they reported that there is not big differential accuracy between multi-layer model and it.

2.2. *Environmental Boundary Conditions*

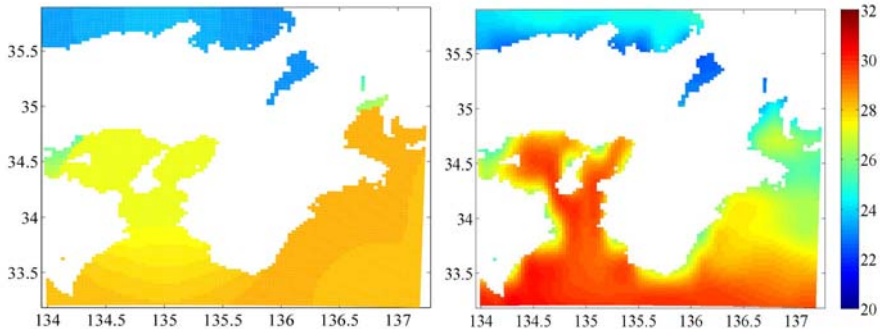
2.2.1. *Basic Configuration of WRF*

The initial and boundary conditions were given by National Centers for Environmental Prediction (NCEP) final operational global analysis data (denotes FNL data, hereafter). The FNL data is 1.0 x 1.0 degree spatial grids horizontally stored every six hours.

As a land-use terrain elevation data, USGS (US Geological Survey) data are used in combination with Japanese GSI (Geographical Survey Institute) land use grid data. The spatial resolutions of USGS topography data and GSI data are 30 seconds x 30 seconds resolution (approximately 100m) and 10m x 10m, respectively. Because the different classifications of land-use categories between two data set, the land-use categories of Japanese GSI is combined with USGS land-use category that are new set land-surface parameters for the WRF model.

2.2.2. *Sea Surface Temperature*

As sea surface temperature, both FNL data and satellite based new generation sea surface temperature for open ocean (NGSST Version 1.0) provided by Tohoku University are used for the analysis. The NGSST is the satellite SST observations from infrared radiometers (AVHRR, MODIS) and a microwave radiometer (AMSR-E) are objectively merged. It is quality-controlled, cloud-free, high-spatial resolution (0.05 degree-gridded) and wide-covering (50 degree x 50 degree), and it provides daily SST digital map. Therefore the NGSST is basically superior to FNL data both accuracy and spatial-temporal resolutions. The snapshot of SST distribution of FNL data and NGSST are shown in Figure 1. Compared with the FNL data, the NGSST has contrast beyond the high temperature range above 30 degree celsius in the south of Osaka bay. There is a difference of more than 3 degree celsius maximally.



(a) FNL data

(b) NGSST

Figure 1. Comparison of SST distribution (2006/8/4)

3. Computational Conditions

The outline of computational domains is shown in Figure 2 and the details of the computational domains in Table 1. Two-way nesting is applied started from domain 1 including the whole of Japan centered on Osaka, to domain 4 finest domain surrounding Osaka. The vertical resolution is 27 layers up to 20km in the altitude, and 4 layers below 2m in the ground. The computational period is the typical summer condition starts from 0:00 29th July to 18:00 7th, August, 2006, and run-up period is until 0:00 1st, August (UTC). The physics of WRF basically follows standard configuration except several near ground conditions. The detail of configuration of the physical scheme is summarized in Table 2.

The target of this study is the urban heat island. Therefore, the ground conditions and related physics are quite important to discuss temperature change near the ground. Following different elements impact to the ground temperature changing the detail land-use data, urban canopy model, SST data are computed.

1. Difference of land-use data between USGS and Japanese GSI data
2. Difference of near ground heat capacity physics by the slab model to the

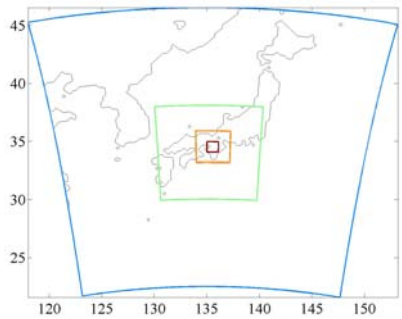


Figure 2. Illustration of computational domain 1-4

Table 1. Details of the computational domain size

domain	Number of horizontal grids	Horizontal resolution	Time step
1	99x99	27 km x 27 km	120 s
2	99x99	9 km x 9 km	40 s
3	99x99	3 km x 3 km	40/3 s
4	99x99	1 km x 1 km	40/9 s

Table 2. The configuration of the physical scheme

	Name of physical scheme
Microphysics	WSM 3-class simple ice scheme
Shortwave Radiation	Dudhia scheme
Longwave Radiation	RRTM scheme
Surface Layer	Similarity scheme
Land Surface	Noah land-surface model
Planetary Boundary Layer	Mellor-Yamada-Janjic model
Cumulus Parameterization	Kain-Fritsch scheme

urban canopy model

3. Impact of SST to Osaka by the FNL data and NGSST

The changing the combination of these physics and conditions, the best reproducibility of ground temperature are examined in the summer of Osaka.

Finally, the impact on urban heat environment due to change of sea surface temperature is calculated as test assessment case. For the pseudo sea warming test, the sensitivity of SST plus 1 degree condition is used. Without changing the parameters and conditions such as vegetation and land surface except SST, the impact of changes SST to urban temperature near coast mega city is considered.

4. Result and Discussion

4.1. *Reproducibility of Urban Heat Environment*

Besides describing the in detail, it is examined the relationship between spatial resolution and estimation accuracy. In addition, it is verified that the result of domain 4 gave the smallest average absolute error and rms error of ground temperature rather than other coarse domains in comparison with observed data of AMeDAS. Therefore, we focus on the results of the domain 4 for the assessment of Osaka urban climate following section. Figure 3 (upper) shows the time series of observed data and numerical results of temperature at 2 m above the ground at Osaka point, and Figure 3 (lower) shows the difference between the observed data and numerical results. The blue colored line represents AMeDAS observed value, the peach colored lines represent the simulation results conducted on the default condition of the WRF (1), the green colored lines represent the simulation results using Japanese GSI data (2), the red colored lines represent the simulation results applying urban canopy model and GSI data (3), and the black colored lines represent the simulation results using NGSST, urban canopy model and GSI data (4). Comparing to the simulation result, there are significant difference in the night temperature. The accuracy of day time temperature is reasonable in comparison with the observed data. The accuracy of night temperature estimation is increased considering different elements. The average minimum temperatures of case (2) – (4) for 7 days are raised 1.0, 2.9, 0.3 degrees from default condition, respectively. Since the significant change occurs whether to apply urban canopy model, it has big impact on the peak temperature in the Osaka urban area. Compared with 12 AMeDAS points average temperature around the Osaka plain, the differences between the estimated and observed temperatures at 4 points classified as ‘urban area’ are smaller than the one at 8 points classified as ‘non-urban area’. From these results, land surface parameters of classified non-urban land, such as fields

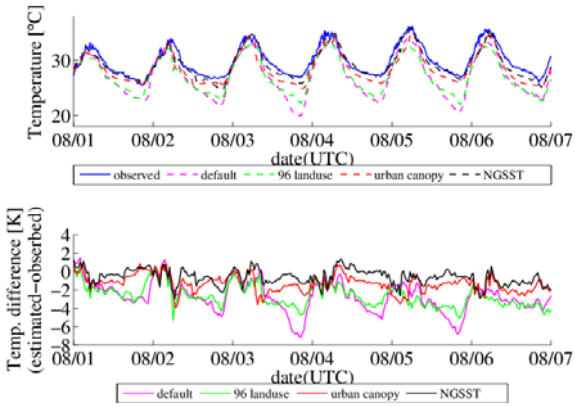


Figure 3. Time series of temperature 2 m at Osaka point (2006/8/1-7)

and forests are not well adjusted to the Japan (or East Asia). On the other hand, looking at 12 AMeDAS points, the average temperature deviation from the observation is 0.7 degrees, and its variance is 0.46. The averaged error of 0.7 degrees includes the both errors of WRF model itself and the influence of anthropogenic heat.

4.2. *Influence of Sea Surface Temperature on Urban Area*

Figure 4 shows the time series of temperature 2 m above the ground in the cases of observed SST and +1 degree increased SST condition at Osaka point. At the land side of Osaka point, the SST changes makes +0.6 degree increase in the average temperature, +0.4 degree increase in the maximum temperature, +0.5 degree increase in the lowest temperature during the computational period. The average temperature among 7 points located near the coast are 0.7, 0.5 and 0.7 degree, and the average temperature among 5 points located inland side are 0.5, 0.3 and 0.7 degree, respectively. On the other hand, Figure 5 shows the wind direction and temperature difference between two configurations at 14:00 (UTC), of 4th, August. The contour indicates the temperature difference due to +1 degree increased SST, the black and white vectors show wind distribution before and after. The temperature rise due to increased SST affect not only coastal area but also inland area. Front of sea breeze of simulation in the normal condition is reached to the inland area, but the numerical results with the increased SST give the weaker sea breeze. It might be seen as the results that the duration time of large temperature gradient between land and sea in Osaka becomes shorten, and that the temperature difference between them become smaller in the case of +1 degree increased SST condition. Conversely, the strong sea breeze from the north direction is reached up to the urban area of Osaka.

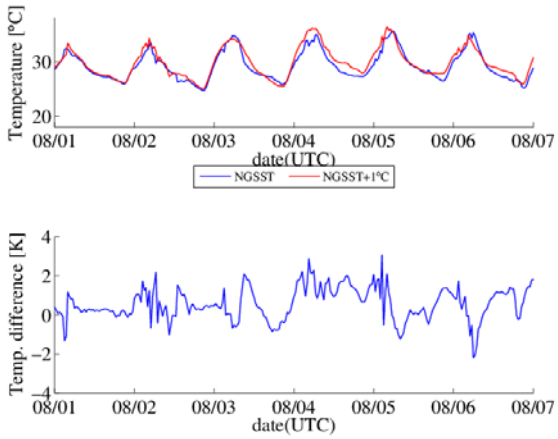


Figure 4. Time series variation temperature 2m at Osaka point of SST rise before and after, and the difference between them

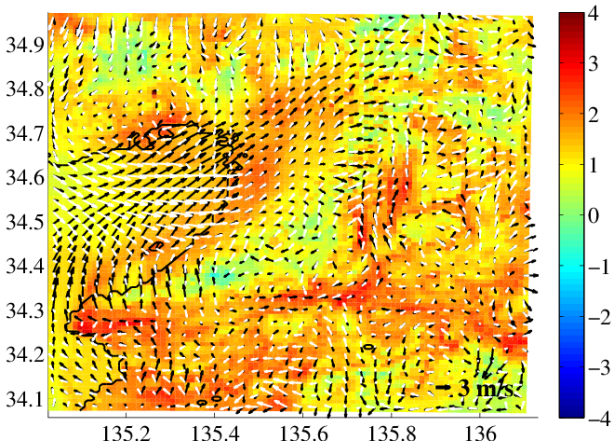


Figure 5. Wind speed and temperature difference distribution of simulation results for 4th August at 14:00 (UTC) (contour: SST rise after – before, black: before rise, white: after rise)

5. Conclusion

It is conducted the atmosphere model simulations for Osaka in the summer, and it is examined the reproducibility of urban thermal environment and the impact of sea surface temperature on urban heat environment. The results can be summarized as follows.

- Reproducibility of atmosphere model in Osaka can be improved by giving accurate land-use data and SST information. The maximum temperature error of simulation is 0.7 degree.
- The SST to rise 1 degree, the average temperature has risen 0.6 degrees around land side of Osaka. In addition, the sea breeze attenuated and the

period of it shortened due to the change in temperature difference above land and sea.

Acknowledgments

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References

1. Japan Meteorological Agency, Bulletin of Heat Island Observation. http://www.data.kishou.go.jp/climate/ (2005).
2. Japan Meteorological Agency, Bulletin of Heat Island Observation. http://www.data.kishou.go.jp/climate/ (2006).
3. D.G. Steyn and T.R. Oke. The depth of the daytime mixed layer at two coastal sites: A model and its validation. *Boundary-Layer Meteorology*, **24**(2):161–180 (1982).
4. Japan Meteorological Agency, Bulletin of Heat Island Observation. http://www.data.kishou.go.jp/climate/ (2007).
5. H. Fujibe. Urbanization Change the Weather. Kagaku, 68(3):238-245 (1998).
6. M. Mizuma. General Aspects of Land and Sea Breezes in Osaka Bay and Surrounding Area. Journal of the Meteorological Society of Japan. Ser. II, 73(6):1029-1040 (1995).
7. K. Yamamoto. Study of the Urban Climate Impact of Urban warming in Osaka Plain. Annuals of Environmental Pollution Control Center, Osaka Prefecture, 23:29-33 (2003).
8. D. Narumi, H. Otani, A. Kondo, Y. Shimoda and M. Mizuno. Urban Heat Environmental Impact of Anthropogenic Heat in City: Study on Improvement of the Urban Heat Island Using Urban Thermal Environment Evaluation Model No.1. Journal of architecture, planning and environmental engineering, (562):97-104, (2002).
9. R. Oda, M. Kanda and R. Moriwaki. Influence of Tokyo Bay Sea Surface Temperature upon Urban Temperature Based on Direct Measurement. Annual Journal of Hydraulic Engineering, 52, (2008).
10. Wei Wang, Dale Barker, John Bray, Cindy Bruyere, Michael Duda, Jimy Dudhia, Dave Gill, and John Michalakes. User ’ s Guide for the Advanced Research WRF (ARW) Modeling System Version 2.2. http://www.mmm.ucar.edu/wrf/, (2007).
11. H. Kusaka and F. Kimura. Coupling a Single-Layer Urban Canopy Model with a Simple Atmospheric Model: Impact on Urban Heat Island Simulation for an Idealized Case. *Journal of the Meteorological Society of Japan*, **82**(1):67–80 (2004).