79: Tokyo localized rainfall simulation using improved urban and sea parameterized WRF-ARW

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Abstract

The uncertainties in weather forecasting have challenged researchers in the capacity of the models to provide reliable forecasts. In mesoscale short-term simulations, these uncertainties are amplified especially for localized heavy rainfall (LHR) events. To address this problem, urban and sea parameters have been improved for the Weather Research and Forecasting (WRF) model. Specifically, the urban parameters considered are the surface roughness (zo), displacement height (zd), and anthropogenic heat emission (AHE). High resolution satellite-observed sea surface temperature (SST) datasets were also inpputed to adequately represent Tokyo bay's condition. The calculation of zo and zd was based from a new aerodynamic parameterization scheme developed from a highly detailed Large Eddy Simulation in Tokyo. AHE was estimated using diurnal proportions from the annual energy consumption in Tokyo for specific energy usage, building classification, and floor count. All urban parameters were prepared at 1000 m. grid spacing. For the SST, daytime and night-time monthly averaged level 3 MODIS SST datasets were linearly interpolated to generate 6-hr intermediate files. Each parameter's contribution to the Tokyo's LHR was simulated at 10-min time resolution with a 240-m grid spacing. 1.0x1.0 degree NCEP FNL Operational Global Analysis datasets were used for other meteorological boundaries. Results were compared with previous studies which use estimates of zd from MacDonald's equation and zo from WRF Urban Canopy Model assumptions. How the updated parameters individually improve the simulation of LHR and further understanding of its formation are presented.

Keywords: urban effect; numerical modelling; WRF

1. Introduction

Numerical weather prediction models have evolved to adequately represent real environmental conditions. An Urban Canopy Model (UCM) was coupled to the Weather Research Forecasting model (WRF) and integrated with the Noah Land Surface Model to simulate urban effects [1,2]. By default, UCM assigns fix surface roughness parameters derived from McDonald equation, and anthropogenic heat values for urban areas: 0.71 for zom (roughness length above canyon for momentum), 7.185 m for d, and 14.4~90 W/m-2. The assumed values are suitable for simulations at wider spatial and longer temporal resolutions (e.g. long-term climate forecasts). However, domains where urban areas are dominantly large are not well represented in detail and may cause some biases when analysing special events such as localized heavy rainfall (LHR).

A new parameterization scheme for zo and d have been recently introduced as a function of average building height, maximum building height, height variance, plane and frontal area indexes. Derived from Large-eddy simulations of real building geometry, it was found that the McDonald's equation underestimates actual surface roughness [3]. Fig. 1 shows the difference of d derived from the new parameterization scheme and McDonald's equation. This research tests the impact of the new parameters to WRF simulations.

This paper summarizes the preliminary findings of this on-going research. Here, a special case of urban-sea interaction within Kanto region is discussed. It starts with the evaluation of the effects of SST, which was found more influential to the rainfall intensity during the simulation period. After evaluating the impacts of SST, the discussion of the surface roughness impacts will also follow.

2. Numerical Set-up

2.1 Boundary Conditions

New parameters were tested into the WRF model. Simulation was conducted with four nests with the third and fourth domains spaced at 1-km and 240-m., respectively. The meteorological boundary condition used was from the NCEP's 6-hr. FNL operational grid analysis data at 1.0x1.0 degrees spatial resolution. UCM was called throughout the simulations. MODIS Sea Surface Temperature (SST) was prepared for the simulation using monthly day and night time SST data linearly interpolated to the desired simulation date.

The new d was incorporated by adding it to the surface topography and neglecting its default UCM value. This assumption is acceptable for simulations with high spatial resolution. Average building height was also incorporated in the model. All surface roughness parameters were inputted in WRF intermediate file formats spaced at 1-km (0.01-deg). The previous study of Shimoju [5] which uses gridded d values from McDonald's equation has much lower d values with differences > 50-m. within the 23 wards of Tokyo (Fig. 1).

2.2 Simulation Date and Cases

Three simulation cases were selected for the same date, August 16, 2008, when an intense localized heavy rainfall (LHR) occurred (Table 1). One day spin-up period was conducted. To provide a clearer understanding of the impacts of roughness, the anthropogenic heat emission (AHE), which is one of the results of Moriwaki et al. [4,5] was fixed for all cases. For additional trials, simulations were also conducted using ECMWF's ERA Interim aside from FNL's. It was found that due to its coarse resolution, SST was not clearly resolved near the coasts thereby generating no rainfall within Tokyo and its surroundings during this day so its results won't be discussed in this paper.

Case	SST	zom (m.)	D (m.)
FNL-CTL	TSK	0.71	7.185
FNL-URB-SST	MODIS	GRID	GRID
FNL-URB	TSK	GRID	GRID

Table 1: Cases with varying combinations of urban and sea parameters simulated at August 15-16, 2008

3. Results and Discussion

3.1 Sea Surface Temperature Effects

FNL uses SST from its skin temperature (TSK). FNL overestimates actual SST's on both Sea of Japan and Pacific Ocean sides (Fig. 2, broken lines represent negative values, thick solid lines represent zero difference). Maximum differences between MODIS and FNL could range from -7.44~6.01 deg C during daytime and -8.13~4.84 deg C during nighttime. Negative values are attributed to the underestimated SST values at Hokuriku region (thin solid lines). This large differences affect greatly the simulated temperature at 2-m. even above ground. MODIS SST also agrees well with the observed SST provided for by the agricultural institute of Kanagawa (not shown).

It can be noticed that during this day a low pressure region developed southeast of Tokyo

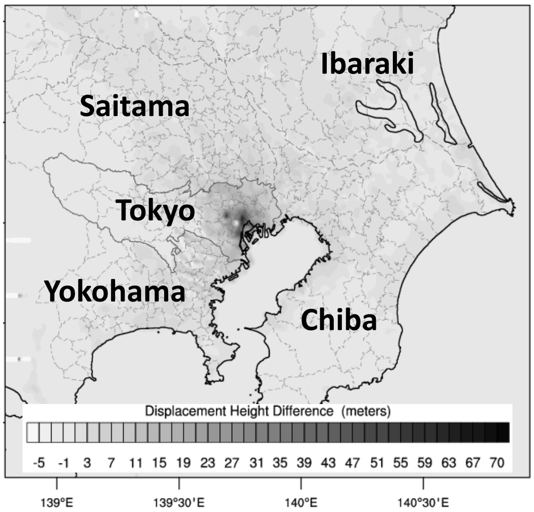

Fig 1.Difference in d calculated by new parameterization and McDonald's Equation at Domain 3

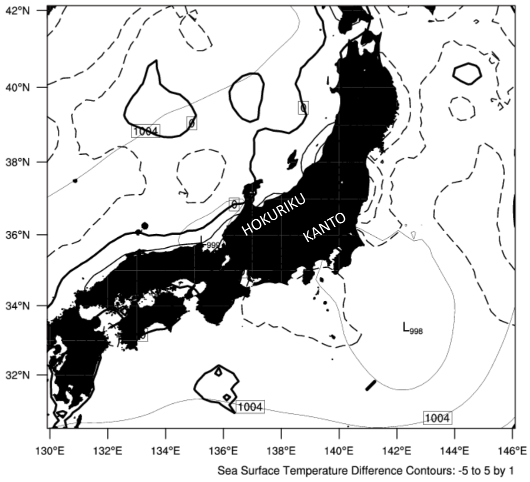

Fig 2.Difference between MODIS SST and FNL TSK; Sea Level Pressure (hPa) at Domain 1

due to the convergence of northeasterly and southeasterly winds (Fig. 3). Driven by the differences in sea level pressure of FNL-URB and FNL-URB-SST, SST influences the wind speed at larger domains. Above sea, FNL overestimates 10-m. wind speed at sea level or at low-level areas (~3m/s). On the contrary, higher elevation on land has underestimated wind speed values. Rain is also overestimated by FNL cases (Fig. 3) due to the large differences in SST.

3.2 Urban and SST Effects to Wind Velocity

To understand the differences in LHR intensity and spatial distribution generated in Fig. 3, earlier condition is first analysed in detail. The parameters obviously affected are the wind, temperature, and heat flux.

During this day, north-easterly winds dominate with occasional flow from the south, close to the surface. At higher elevations, south-westerly winds dominate (Fig.4). This wind pattern contributes to LHR formation which will be discusses later. Combined FNL-URB-SST simulates an earlier inflow of sea breeze from the North-eastern side of Kanto (domain 4). An

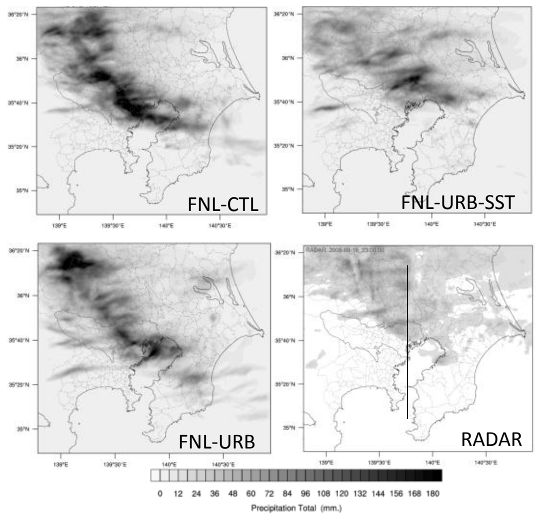

Fig 3. Total rainfall from 1200 to 2400 JST on August 16, 2008; dark vertical strip location of vertical profile

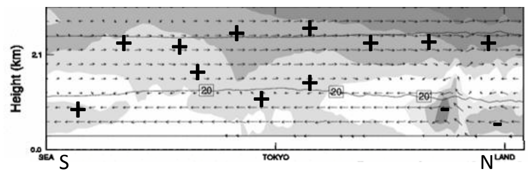

Fig 4. Vertical Profile of Wind Velocity and Temperature; dark palette represents u wind speed (+ means Westerly); vectors represent vw-wind; contour lines represent temperature

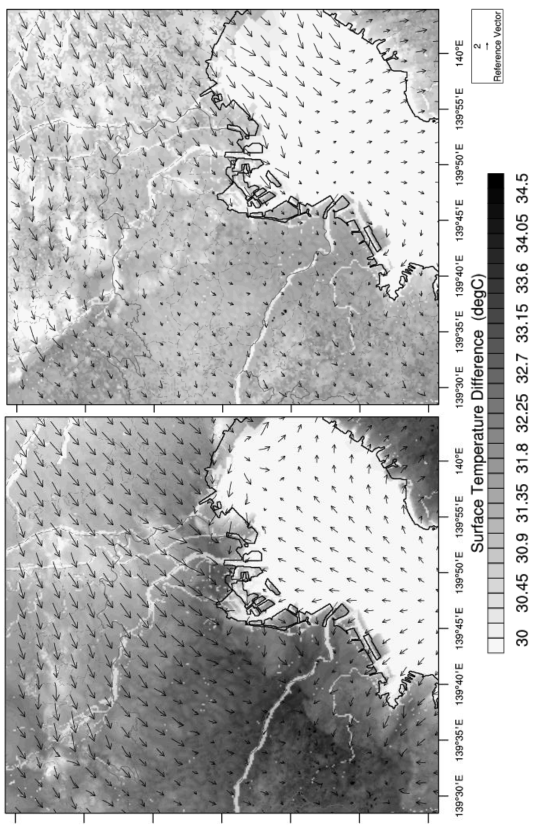

Fig 5. Snapshot at 1330 JST (no simulated rain) of surface temperature T2, and horizontal and vertical velocities, u10, and v10

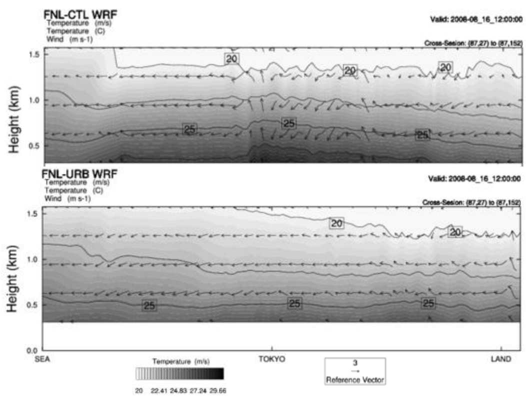

Fig 6. Snapshot at 1200 JST (no simulated rain) of vertical profile of Temperature, and vectors vw-wind

obvious effect of surface roughness is on the simulated 10-m. velocity. Basing from the wind vectors, new parameters clearly stagnates the wind within the city. Wind is diverted to Saitama where surface roughness is lower. Wind velocity is also forced to shift upwards, and upon exiting the city causes downdrafts enabling north-easterly winds to dominate above Tokyo bay (Fig. 5). From noon-time, the advection of colder sea breeze is weakened by the FNL-URBAN unlike the sea breeze front penetration clearly simulated by the FNL-CTL case.

3.3 Urban and SST Effects to Temperature Within The Surface Layer

Focusing attention to FNL-CTL and FNL-URBAN, the skin temperature and temperature at 2-m. are unexpectedly lower (around 3-deg C) for the urban case before the on-set of LHR. One possibility is due to the updated surface roughness parameters which are much larger than the default values used in FNL-CTL case. Increase in building packing, density, and the effective area of heating potentially reduces the amount of heat transported to the ground. It was also found that a larger latent heat flux and ground heat flux was simulated in the URBAN case. The former is due to the effect of the previous day's simulation. The latter is due to the high heat gradient between the atmosphere and the ground. The increase in water vapour reduces the amount of heat in the air dropping the surrounding air temperature.

As the day progresses, the high temperature contour also rises more quickly for the FNL-CTL case above urban canopies compared to the FNL-URB case as shown in Fig. 6. Two possible reasons are cited. First, the faster wind speeds manifested in the FNL-CTL above Tokyo allows larger convergence. Second, FNL-URB with lower surface temperatures also has very low roughness length for heat, zoh, slowing down heat transport above the surface layer. Notice also that downwind of Tokyo, near Tokyo Bay, strong downdrafts can be observed dominating the sea breeze flow from Tokyo bay.

Relating the effect of temperature with the wind pattern differences mentioned earlier, FNL-CTL's T2 is also directly altered by the sea breeze unlike the FNL-URBAN's T2. Near the coasts, the large difference in temperature for the FNL-CTL, represents the inflow of sea breeze and its change in temperature. FNL-URBAN also has cold breeze coming from the dominant north-easterly winds but it does not affect much the temperature at the surface, once again due to the low zoh which is calculated from zom.

3.2 Urban and SST Effects to LHR Generation

It was found that the contribution of surface roughness to the formation of LHR was not as significant compared to that of SST's. In this research, it was found that the LHR was actually less compared to the default setting with the same AHE due to the lesser sensible heat flux, proportional to the surface temperature. If default setting of AHE were used for the FNL-CTL, simulated rainfall would be lesser [5]. Looking back to Fig. 3, the FNL-URB-SS, has the least amount of rainfall among three cases but it matches well with the radar rainfall gauge system provided by the Tokyo Metropolitan Government. From the images alone, the effect of SST is clear. The higher wind velocities, generated by the overestimated TSK (representative of SST) of FNL, causes water vapour concentrations biased at western side of Saitama.

The improved surface parameters also cause rainfall to occur higher at the north-east border of Tokyo Metropolitan Area. The easy transport of moisture from the wind convergence using default UCM settings overestimates rainfall above Tokyo as well as some parts of Chiba. Vapor mixing ratio at 2-m. was simulated higher for the FNL-URB case. The surface roughness contributes in the reduction of rainfall at the center of Tokyo due to the stagnated water vapor close to the ground.

4. Conclusion

An improved WRF model was proposed and initially tested. New parameterization of surface roughness and displacement heights were applied to the model. 1-km spaced grids of zom, d, real building height for Kanto region and high-resolution MODIS SST was inputted as surface boundaries during the simulation of LHR on August 16, 2008. Significant improvements were found in the generation of LHR.

The accuracy and distribution of SST along the coasts has significant impact in the simulation of LHR. The realistic SST remedied the problem of overestimated rainfall simulated above Saitama Prefecture. Furthermore, the distribution of total LHR was corrected by the surface roughness.

Sea breeze penetration was also altered by the new roughness parameters. The impact of surface roughness was clearly seen in the reduced wind velocities above Tokyo. Downwind wind velocities were also affected proven by the increased and reverse 10-m. wind velocity simulated at Tokyo Bay.

Some problems were encountered which cannot be explained by the current single simulation period. For example, the onset of solar radiation was delayed for the FNL-URB even if no clouds were found at upper levels. Possibly due to the weather condition simulated during the spin-up period, it was not clear why latent heat flux were simulated higher for FNL-URB case as well. Simulations during dry conditions will be conducted in the future using the advanced settings and ensemble will be made.

5. Acknowledgements

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7. References

1. Skamarock, W. C., J.B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J.G. Powers, (2005). A description of the Advanced Research WRF Version 2. *NCAR Tech Notes*-468+STR.

2. D. Kusaka H., and F. Kimura, (2004). Coupling of a single-layer urban canopy model with a simple atmospheric model: Impact on Urban Heat Island simulation for an idealized case. *Journal of Meteorological Society of Japan*, 82, 67-80.

3. Miyamoto, T., A. Inagaki, and M. Kanda, (2012). Urban aerodynamic parameterization for Tokyo 80 districts by using large-eddy simulation with 3D building GIS. *Annual Journal of Hydraulic Engineering, JSCE*, 56. (in Japanese)

4. Moriwaki, R., M. Kanda, H. Senno, A. Hagishima, and T. Kinouchi, (2007). Anthropogenic water vapor emissions in Tokyo. *Water Resources Research*, 44., W11424.

5. Shimoju R., M. Nakayoshi, and M. Kanda, (2010). Case analyses of localized heavy rain in Kanto considering urban parameters. *Annual Journal of Hydraulic Engineering*, JSCE, 54., pp. 349-354. (in Japanese)