ULTRA-HIGH RESOLUTION AND NONSTATIONARY SIMULATION TO UNDERSTAND HEAT STORAGE MECHANISM IN URBAN AREA I

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Abstract

Three dimensional radiation processes was introduced to Multi-Scale Simulator for the Geoenvironment (MSSG), for the purpose of understand heat storage mechanism in urban canyon area. In three dimensional radiation processes, Monte Carlo method is adopted to calculate the building form coefficient in computation of three radiation processes. In preliminary simulations with MSSG-A including three dimensional radiation processes, impacts of albedo to heat storage process in urban area is considered in our simulations. Simulations suggest that radiation processes tends to increase instability in lower boundary layers in urban canopy area.

Key words: urban canyon, three dimensional radiation processes, heat transfer, meso-scale weather prediction

1. INTRODUCTION

Three dimensional radiation processes was introduced to Multi-Scale Simulator for the Geoenvironment (MSSG), for the purpose of understand heat storage mechanism in urban canyon area. It is indispensable that three dimensional radiation processes among surface on buildings and roads should be validated how large impact brings the heat storage system in urban area. In this research, Monte Carlo method is adopted to calculate the building form coefficient in computation of three radiation processes. Although Monte Carlo method is required to highly computational cost, it is useful to validate three dimensional radiation processes taking account the overhead situation is automatically detected pursuing individual particles. Furthermore, in MSSG, changing albedo of the surface of buildings and of surface of road is controlled easily, therefore, impacts of albedo to heat storage process in urban area will be considered in our simulations. In this presentation, we will present preliminary results of simulations with three dimensional radiation processes under changing albedo in the real urban canopy. The heating/storage processes in a real urban city will be discussed through analyzing of the results from ultra-high resolution and non-stationary simulations.

2. MSSG AND THREE DIMENSTIONAL RADIATION PROCESS MODEL

2.1. MSSG model configuration

Multi-Scale Simulator for the Geoenvironment (MSSG), which is a coupled non-hydrostatic atmosphere-ocean-land global circulation model, has been developed for the purposed of promoting advanced prediction simulation. MSSG is optimized to be run on the Earth Simulator with high computational performance and it is designed to be available with flexibility for different space and time scales. MSSG can simulate phenomena with ultra high small scale such as several meters for horizontal resolution which is required in simulations in urban canyon. MSSG enable us to global atmospheric simulation with 1.9km horizontal resolution. MSSG is designed in order to provide the flexibility for forecasting weather/climate variability as follows,

- Global non-hydrostatic atmospheric circulation model: Global MSSG-A,
- Regional non-hydrostatic atmospheric model: Regional MSSG-A,
- Global non-hydrostatic/hydrostatic ocean model: Global MSSG-O,
- Regional non-hydrostatic/hydrostatic ocean model: Regional MSSG-O,
- Couple Global MSSG-A to Global MSSG-O: MSSG,
- Coupled Regional MSSG-A to Regional MSSG-O: Regional MSSG,

and global coupled model MSSG is capable to connect to Regional coupled model MSSG using 1-way/2-way nesting schemes. Here MSSG-A and MSSG-O are an atmpspheric component and a ocean componenet of MSSG, respectively.

In this study, we mainly used MSSG-A for urban simulation. MSSG-A is a non-hydrostatic global/regional atmosphere circulation model. MSSG-A is compromised of fully compressive flux form of Satomura (2003), Smagorinsky-Lilly type parameterizations by Lilly (1962) and Smagorinsky (1965) for sub-grid scale mixing, surface fluxes by Zhang (1982) and Blackadar (1979), cloud microphysics with mixed phases by Reisner (1998) and cumulus convective processes by Kain (1993) and Fritsch (1980). Cloud-radiation scheme for long wave and shortwave interactions with both explicit cloud and clear-air are adopted which is based on the scheme in MM5. Over land, the ground temperature and ground moisture are computed by using a bucket model. As upper boundary condition, Rayleigh friction layer is set.

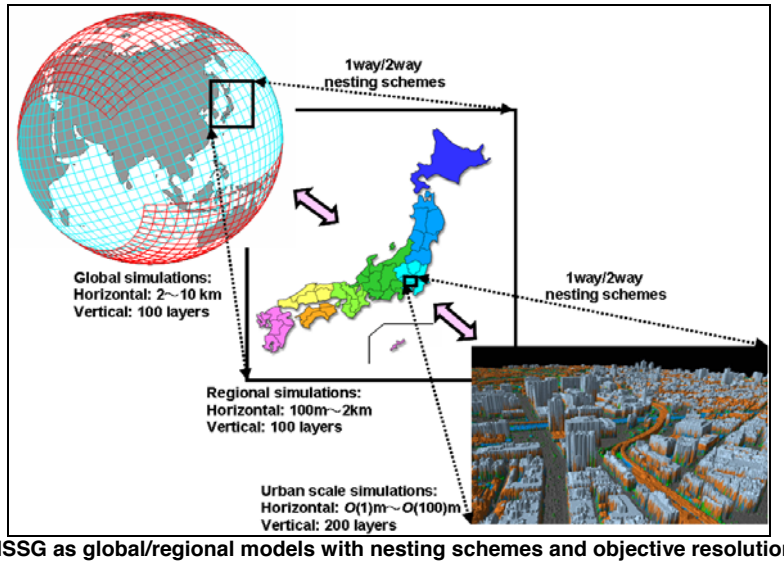


Fig. 1. Scale of MSSG as global/regional models with nesting schemes and objective resolution for each scale.

In MSSG, Yin-Yang grid system presented in Kageyama (2004) and Arakawa C grid is used. The atmospheric component utilizes the terrain following vertical coordinate with Lorenz type variables distribution in Gal-Chen (1975). The ocean component uses the z-coordinate system for the vertical direction. In discritization of time, the 2nd, 3rd and 4th Runge-Kutta schemes and leap-flog schemes with Robert-Asselin time filter are available. The 3rd Runge-Kutta scheme presented in Wicker (2002) is adopted for the atmosphere component. The vertical speed of sound in the atmosphere is dominant comparing with horizontal speed, because vertical discritization is tend to be finer than horizontal discritization. From those reasons, horizontally explicit vertical implicit (HEVI) scheme in Durran (1991) is adopted in MSSG-A.

Conservation scheme was discussed in Peng (2006) and no side effects of over lapped grid system such as Yin-Yang grid were presented due to validations results of various benchmark experiments in Takahashi (2004a, b) and Takahashi (2005). Therefore, MSSG-A can deal with precipitation processes such as used in weather prediction for urban simulation.

2.2. Outline of three dimensional radiation processes model

Three dimensional radiation processes among walls on buildings and roads is considered as one of strong impacts to heat storage system and being indispensable for simulation/understanding of heat island phenomena. In this research, Monte Carlo method is adopted to calculate the building coefficients Fij and Fji. Although Monte Carlo method is required to high computational cost, the overhead situation in radiation processes is automatically detected through the processes of pursuing individual particles. Furthermore, in calculation of the building form coefficient, the coefficients with high accuracy can be computed by using the fewer numbers of particles using characteristics of its symmetry. The radiation heat transmission process on an arbitrary grid should be considered the reflection of the heat radiation on other arbitrary grid. Those all processes are considered in calculation of heat radiation energy G_i (Fig. *).

Suppose Ti, Tj are surfaces are temperature on surfaces Ai and Aj, respectively, amount of heat radiation is calculated by the following equation.

$$Q_{ij} = \sigma (T_1^{4_i} - T_j^{4_i}) A_i F_{ij} = \sigma (T_1^{4_i} - T_j^{4_i}) A_j F_{ji} .$$

Here Fij, Fji are building coefficients betweenaurfaces Ai and Aj defined as follows,

$$F_{ij} = \frac{1}{A_i} \int_{Ai} \int_{Aj} \frac{\cos\beta_i \cos\beta_j dA_i dA_j}{\pi r^2} \quad \text{and} \quad F_{ji} = \frac{1}{A_j} \int_{Ai} \int_{Aj} \frac{\cos\beta_i \cos\beta_j dA_i dA_j}{\pi r^2} .$$

Heat radiation energy Gi from surface i should be capculated by considering any reflactions between any grids on a wall surface.Gi on any wall in unit area for each unit time is discribed as a follow equation.

$$G_i = \varepsilon_i \sigma T_i^4 + \frac{(1-\alpha_i)}{A_i} \sum_{k=1}^{n} A_k G_k F_{ki}$$

Where, G_i : Heat radiation energy from surcale of wall i [W/m^2], α_i : rate of absorption on surface i, ε_i : rate of radiation on surface, and σ : Stefan-Bolzman's constant; 5.67×10^{-8}[W/m^{2}K^4].

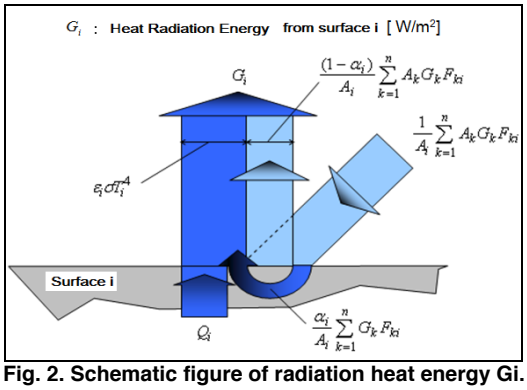


Fig. 2. Schematic figure of radiation heat energy Gi.

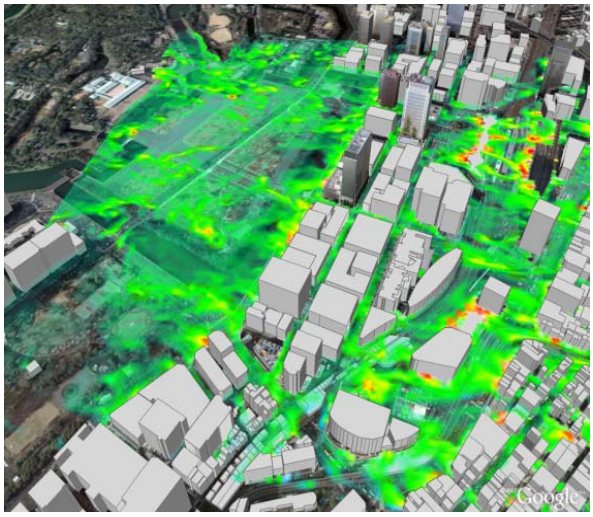
3. RESULTS

3.1. Nonstationaly simulation in urban area

Simulations were possible by MSSG-A coupled by the three radiation process model. Snapshot of the simulation is presents in Fig.3. The initial state was settled at 15:00 on 5th August in 2005.Initial thermal condition was set taking account of rate of shade in a day. Snapshot of 15 minutes simulation from the initial state by using MSSG coupled the 3D radiation model is presented in Fig.3. Temperature distribution is shown at the height of 7.5m from the ground. Eddies streams were simulated very well, therefore it suggest that these simulation will be quite useful to assesse on issues of heat contents for the heat island.



(a) picture of simulation area form a aircraft.



(b) temperature distribution is shown at the height of 7.5m from the ground.

Fig.3. Snapshot of 15 minutes simulation from the initial state by using MSSG coupled the 3D radiation model.

3.2. Impact of three dimensional radiation processes

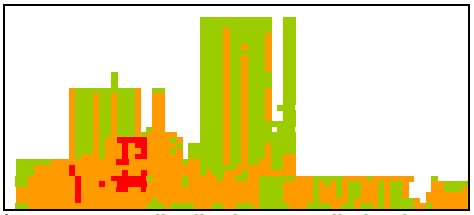
It aimed to understand deatails of heat radiation mechanism in urban canyon area and three dimensional radiation process model was developed. It is indispensable for simulation of heat island phenomena influenced from thermal storage process among walls on building and road. Heat tends to be stored in lower level in city canopy layer and its tendency was appeared on walls toward the all direction as shown in Fig.4. Furthermore, eddied due to convection we trapped in the city canopy layer shown as in Fig5.

4.DISCUSSION AND FUTURE WORK

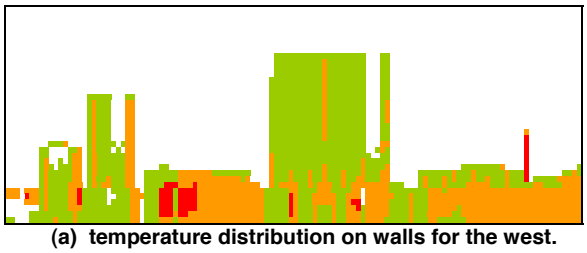
In those preliminary simulation results, three dimensional radiation process suggests effects to lower boundary layer. It means heat content processs tends to be stored in lower level and increase instability in urban canopy. Furthermore, coupling urban-scale to Meso-scale phenomena may be important to understand heat island mechanism explicitly. In near future, we are planning to apply simulations of heavy rain in urban area with urban-scale MSSG-A including three dimensional radiation processes.



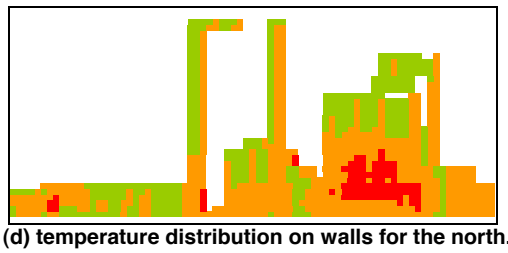
(a) temperature distribution on walls for the east.



(b) temperature distribution on walls for the south.



(a) temperature distribution on walls for the west.



(d) temperature distribution on walls for the north.

Fig.4. Differences of temperature distribution between with 3D radiation process model and without the model.

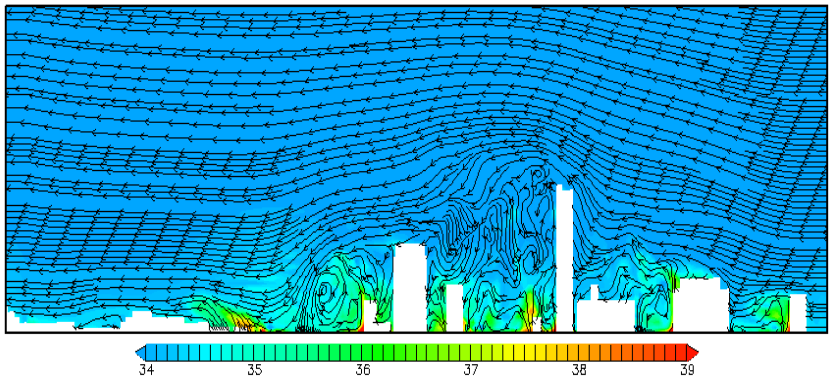


Fig.5. Wind stream function and temperature distribution in for the vertical.

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