Multi-Scale Weather/Climate Simulations with Multi-Scale Simulator for the Geoenvironment (MSSG) on the Earth Simulator

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Multi-Scale Simulator for the Geoenvironment (MSSG), which is a coupled non-hydrostatic atmosphere-ocean-land model, has been developed in the Earth Simulator Center. Outline of MSSG is introduced and characteristics are presented. In this report, we focus on model component of urban scale phenomena and cloud physics in meso-scale. In addition, in the purpose of longer simulation, sea ice model was introduced in MSSG in this fiscal year. In this section, it is reported the outline of simulation results and those impacts.

Keywords: Coupled atmosphere-ocean model, multi-scale, multi-physics, high performance computing, the Earth Simulator

1. Introduction

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 (Fig. 1). 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.

In the development of MSSG, we especially focus on the following thema;

I. improvement of accuracy of discritization schemes for ultra high resolution simulation,
II. improvement of physical performance of boundary layer and micro cloud physics with turbulent scale effects,
and
III. improvement of forecasting results with multi-scale simulations.

This report summarizes results of our project in FY2007.

2. MSSG model configuration

An atmospheric component of MSSG, which we call it 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-radia-

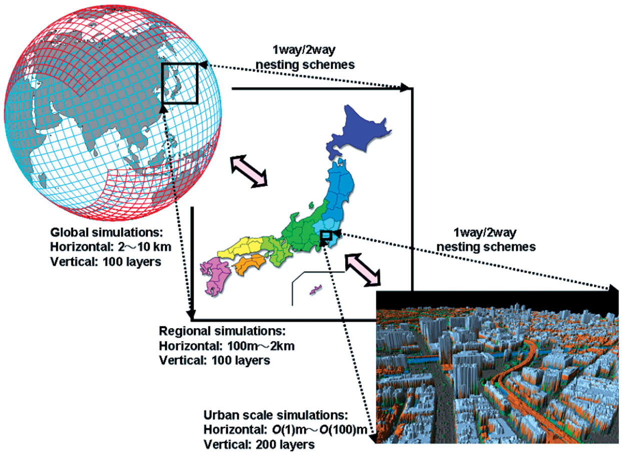


Fig. 1 Scale of MSSG as global/regional models with nesting schemes and resolution.

tion 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.

In the ocean component, which we call it MSSG-O, in-compressive and hydrostatic/nonhydrostatic equations with the Boussinesq approximation are introduced based on describing in Marshall (1997a) and Marshall (1997b). Smagorinsky type scheme by Lilly (1962) and Smagorinsky (1965) is used for the sub-grid scale mixing. Algebraic Multi-Grid (AMG) method in Stuben (1999) is used in order to solve a Poisson equation in MSSG-O. AMG is well known as an optimal solution method. In MSSG, we used the AMG library based on aggregation-type AMG in Davies (1976), which has been developed by Fuji Research Institute Corporation.

In both the atmospheric and ocean components, 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 2^{nd}, 3^{rd} and 4^{th} Runge-Kutta schemes and leap-flog schemes with Robert-Asselin time filter are available. The 3^{rd} Runge-Kutta scheme presented in Wicker (2002) is adopted for the atmosphere component. In the ocean component, leap-flog schemes with Robert-Asselin time filter is used for the ocean component. For momentum and tracer advection computations, several discritization schemes introduced in Peng (2004) are available. In this study, the 5^{th} order upwind scheme is used for the atmosphere and central difference is utilized in the ocean 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).

3. Computational/ physical model improvements

In FY2007, we especially focus on developing model component of urban scale phenomena and cloud physics in meso-scale. In addition, in the purpose of longer simulation, sea ice model was introduced in MSSG. In this section, it is reported the outline of simulation results and those impacts.

3.1 Impact of three dimensional radiation model in urban canyon

Three dimensional radiation process model was developed in order to understand heat radiation mechanism in urban canyon area. It is indispensable for simulation of heat island phenomena influenced from thermal storage process among walls on building and roads. Heat tends to be stored in lower level in city canyon layers and its tendency was appeared on walls toward the all direction as shown in Fig. 2. Furthermore, eddies due to convection were trapped

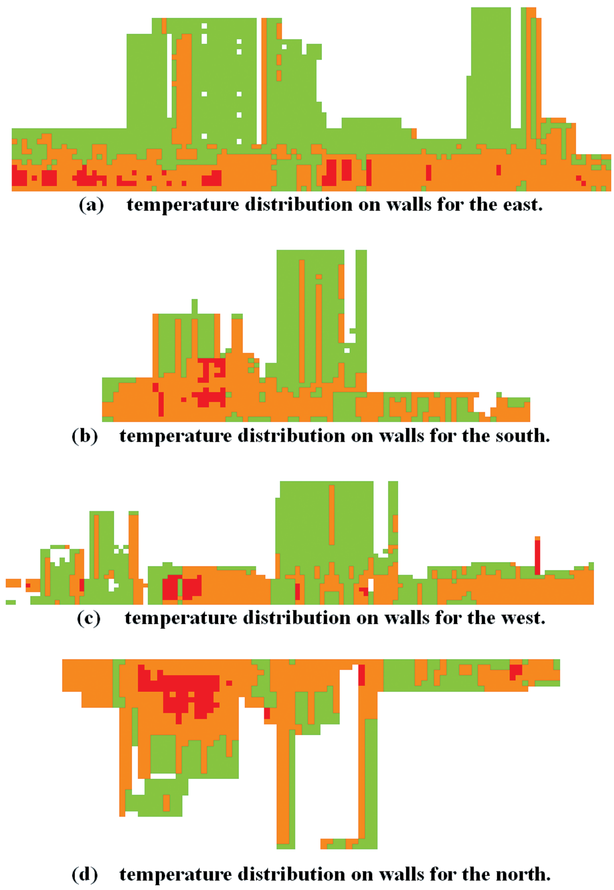


Fig. 2 Differences of temperature distribution between with 3D radiation process model and without the model.

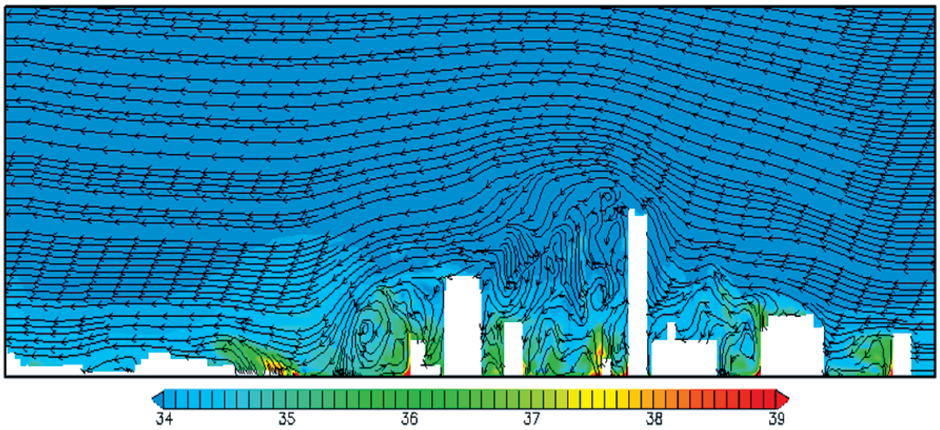
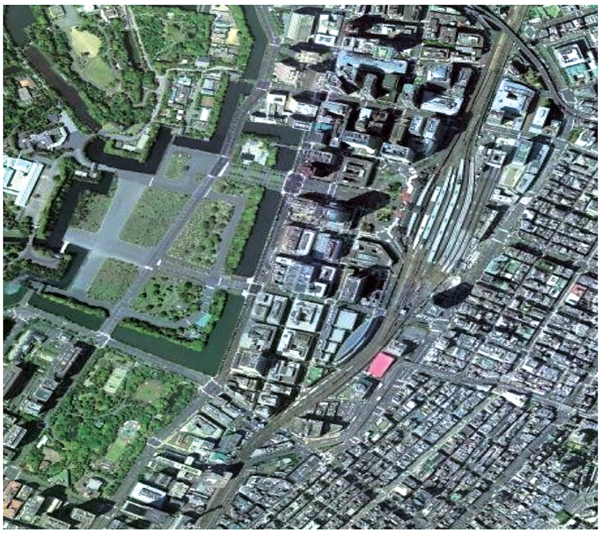
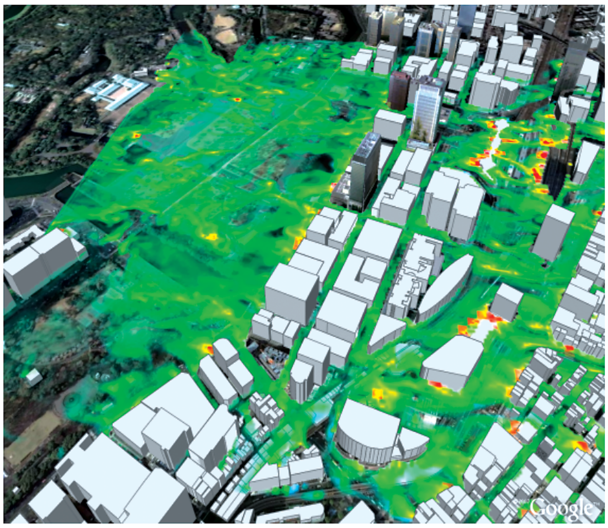


Fig. 3 Wind stream function and temperature distribution in for the vertical.



(a) Picture of simulation area form a aircraft.



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

Fig. 4 Snapshot of 15 minutes simulation from the initial state by using MSSG coupled the 3D radiation model.

in the city canyon layers shown as 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 integration from the initial state by using MSSG coupled the 3D radiation model is presented in Fig. 4. Temperature distribution is shown at the height of 7.5 m from the ground. Eddies and wind streams were simulated very well, therefore it suggest that these simulation will be quite useful to assesse measures for the heat island. Furthermore, it will be required to introduce further efficient computational schemes to be simulated it faster.

3.2 Efficient computational scheme for Bin method using CIP method.

In the cloud physics processes, especially Bin methods, during the collision growth process with which the cloud condensation nucleus is activated and a minute drop of water or a minute ice crystal is generated, condensation and the evaporation growth process is simulated. Condensation and the evaporation process are especially important processes and connecting directly with the stability of the dynamic computation to accompany the thermal change by the phase change. However the computational cost is extremely high. Development of the calculation method with not only high accuracy but low computational cost is required.

In this study, Condensation and the collision calculation method used the CIP-CSLR(Constrained Interpolated Profile-Conservative Semi-Lagrangian with Rational function) method were developed. Figure 5 shows one example of the result. The CIP-CSLR method shows best performance due to represent peak value and profile comparing the reference as shown in Fig. 5. In addition, further characteristics of the CIP-CSLR become clear as follows; numerical value diffusion is small, numerical oscillation is not caused, the 2nd order of accuracy is maintained, conservation low is kept for the whole computation, and computational cost is quite low. Computaional cost is 4-5 times more compared

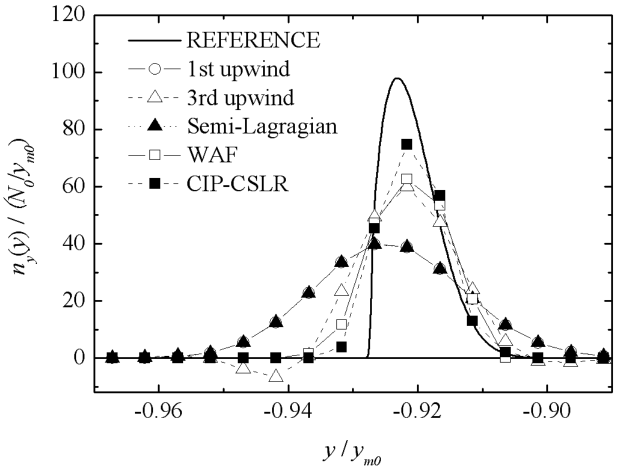


Fig. 5 Performance to represent peak value and profile comparing the reference.

Table 1 Computational cost of the each scheme during 1,000 integration steps.

Computation scheme	Computational cost	Ratio of cost
1st order upwind	1733127	1.000
3rd order upwind	2398127	1.384
Semi Lagrangean	5783127	3.337
WAF	2500841	1.443
CIP-CSLR	7580126	4.374

with cost of the 1st order upwind scheme, however, 0.4 times of the computational time is realized using 10 times longer time step as shown in Table 1.

3.3 Sea ice model component introduced in MSSG and its performance

Coupling ocean physics to sea ice production plays quite important to simulate seasonal, annual or more longer simulation such as climate variability simulations. The introduced sea ice model is taking account of sea ice collision process. The collision process is considered as quite important process to represent real sea ice distribution, because radiation process in the atmosphere is influenced by the distribution and mixed layer in the ocean as well. Especially, ultra high resolution simulation is required to understand the impact to Japanese climate system by intermediate water formation in the Okhotsk Sea. Preliminary experiments were promoted in the current year to represent sea ice distribution by the new introduced model with MSSG-O. The initial state was used climatological data of November and seven months integration was executed. Figure 6 shows observational data of sea ice distribution and its condensation distribution on 28th February 2007 as an case data. Snapshot of the simulation in Fig. 7 is comparable to the observational data. Sea ice collision effects are remarkable

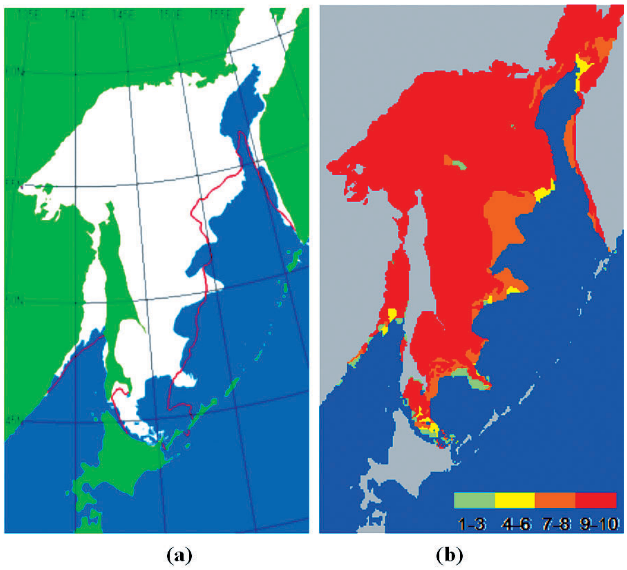


Fig. 6 Observation data on 28th February 2007. (a) sea ice distribution (b) sea ice consentration.

Fig. 7 Snapshot of consentration distribution on 28th February using MSSG coupled to the introduced sea ice model.

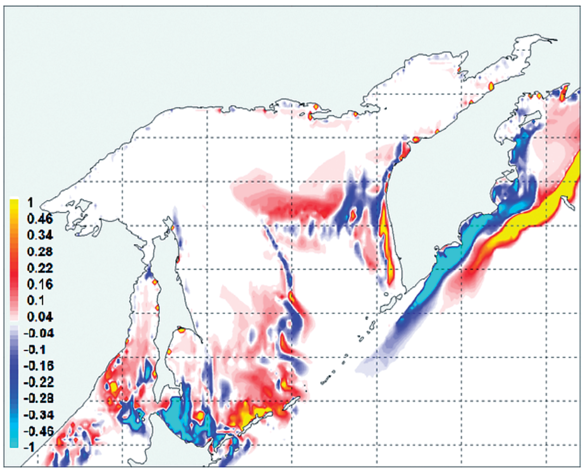


Fig. 8 Comparison of distribution sea ice consentration between simulation result using sea ice collision effects and results without collision effects.

in the front of sea ice distribution as shown in Fig. 8. Furthermore, distribution of sea ice in the Okhotsk Sea, especially the region with low concentration was improved compared with simulation results from the MSSG-O without sea ice collision process.

4. Conclusion and near future work

In the current year, we focus on developing model component such as three dimensional radiation system, high performance computational scheme for cloud micro-physics of Bin method, and the sea ice model with collision processes. Though results were not presented in this report, local wind forecasting or precipitation forecasting in meso-scale region had been improved. Through these experiments and developing model components, various scale simulations will be planned in the near future. Especially, seasonal/annual forecasting will be promoted using MSSG with cloud resolved scale.

地球シミュレータ用非静力学大気海洋結合モデル (Multi-Scale Simulator for the Geoenvironment: MSSG)の開発

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キーワード：Coupled atmosphere-ocean model, multi-scale, multi-physics, high performance computing, the Earth Simulator

本年度は、非静力学大気海洋結合モデル(Multi-Scale Simulator for the Geoenvironment: MSSG)の開発において、モデルのコンポーネントの高度化に注力した。特に、都市における蓄熱メカニズムの解明において必須となる都市キャニオンにおける3次元放射過程モデルを構築し、さらに、鉛直座標系を異なるスケール間で連続的に結合可能なハイブリッド鉛直座標を導入することで、都市スケールの建物群を解像可能にした。これらのモデルをMSSGと結合し、都市スケールとメソスケールをシームレスに連成計算が可能となる拡張MSSGを構築した(Fig. 1)。また、気象や気候変動予測において重要なモデルである雲解像スキーム(Bin法)の計算効率を向上するために、衝突成長過程や凝縮・蒸発成長過程に対する計算にCIP-CSLR (Constrained Interpolated Profile-Conservative Semi-Lagrangian with Rational function)法を用いた新しい計算手法を開発し、従来の1次風上差分法と比較して計算量は4～5倍多くなるが、時間刻み幅を10倍長くすることにより、全体として約0.4倍の計算量で凝縮・衝突計算を実行することを可能とした。さらに、この新たな手法は、従来の手法に比較して、数値拡散が小さく安定、高精度であり、粒子数保存を厳密に満たすことを明らかにした。加えて、季節変動予測、および気候変動予測などにおいては必須のモデルとなる海氷モデルを開発した。本海氷モデルは、海氷間の衝突を考慮した新しいモデルであり、MSSG-Oの静力学および非静力学のどちらのバージョンにも対応できるように実装されている。海氷間の衝突の影響は、海氷が生成されるフロントにおいて大きいことが示唆されており、海氷分布の予測や海洋混合層の形成過程においても影響を与える可能性がある。

本年度までの開発によって、気象、気候変動予測に必要なモデルコンポーネントの導入が終了し、複数スケール間の影響を直接扱うことが可能なモデルとしてのMSSGを構築した。今後は、これらのモデルコンポーネントのさらなる高度化と計算性能の向上を推進するとともに、結合モデルとしてのMSSGを用いて具体的なマルチスケール現象のシミュレーションおよび高解像度での数週間から数カ月の事例予測に着手する予定である。

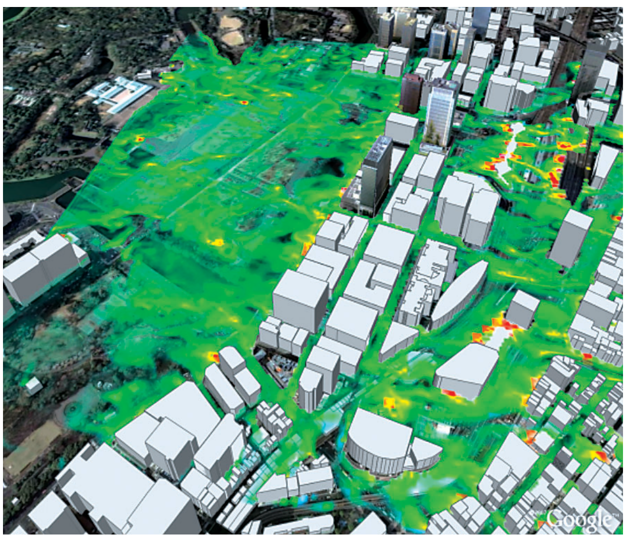

Fig. 1 Snapshot of 15 minutes simulation from the initial state by using MSSG coupled the 3D radiation model.

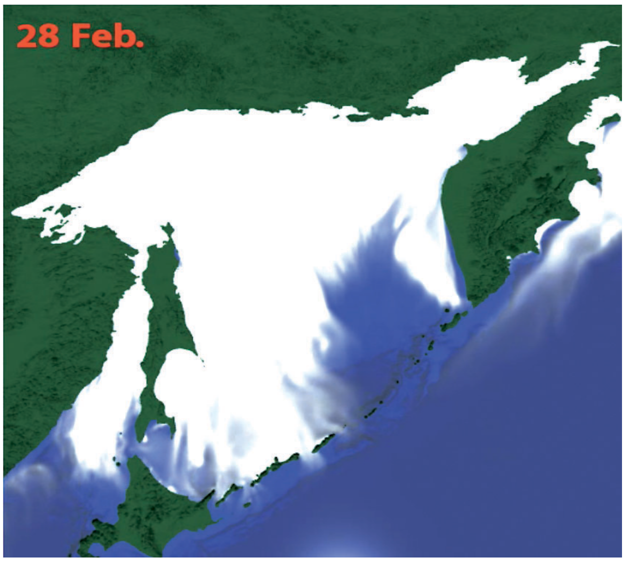

Fig. 2 Snapshot of condensation distribution on 28th February using MSSG coupled to the introduced sea ice model.