Adaptation Oriented Simulations for Climate Variability

Project Representative
Keiko Takahashi Earth Simulator Center, Japan Agency for Marine-Earth Science and Technology

Authors
Keiko Takahashi[*1], Ryo Ohnishi[*1], Yuya Baba[*1], Shinichiro Kida[*1], Keigo Matsuda[*1], Li-Feng Lu[*1], Youngjin Choi[*1], Koji Goto[*2] and Hiromitsu Fuchigami[*3]
*1 Earth Simulator Center, Japan Agency for Marine-Earth Science and Technology
*2 NEC Corporation
*3 NEC Informatec Systems LTD

A coupled atmosphere-ocean-land model MSSG has been developed in the Earth Simulator Center, which is designed to model multi-scale interactions among the atmosphere, the ocean and the coupled system. Aiming to seamless simulation to understand mechanisms of radiation micro-physics, impacts of ocean effects to urban environment and heavy rain which are suffer in the future, models and simulations results with the model are introduced in this report.

Keywords: Coupled atmosphere-ocean model, urban cities, heat island phenomena, heavy rain, adaptation

1. Introduction

Multi-Scale Simulator for the Geoenvironment (MSSG), which is a coupled atmosphere-ocean-land global circulation model, has been developed for seamless simulation based on multi-scale multi-physics modeling strategy in order to predict not only weather but climate variability. 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 [1, 2, 3, 4, 5]. In this report, summarizes a part of results of this project in FY2013 that focus on the following themes to execute seamless simulations with MSSG.

- In order to improve radiation process model for cloud process and urban scale distribution of temperature, three-dimensional direct numerical simulation was introduced and development of the improved three dimensional radiation model was promoted.
- In order to understand the effect of sea surface temperature in Tokyo Bay, investigation of impact to sea surface temperature from the wind distribution and resolution.
- Impact of roughness length to heavy rain representation is studies considering special deviation of buildings in urban area.

2. Improvement in radiation physics

The influence of turbulent clustering and entrainment of cloud droplets on the radar reflectivity factor is investigated. A three-dimensional direct numerical simulation of particle-laden isotropic turbulence is performed to obtain turbulent clustering data (Fig. 1). The clustering data is then used to calculate the power spectra of droplet number density fluctuations, which show a dependence on the Taylor microscale-based Reynolds number Re_λ and the Stokes number St. The Reynolds number dependency of the turbulent clustering influence is investigated for $127<Re_\lambda<531$. The spectra for this wide range of Re_λ values reveal that $Re_\lambda=204$ is sufficiently large to be representative of the whole wavenumber range relevant for radar observations of atmospheric clouds (Fig. 2). We then investigate the Stokes number dependency for $Re_\lambda=204$ and propose an empirical model for the turbulent clustering influence assuming power laws for

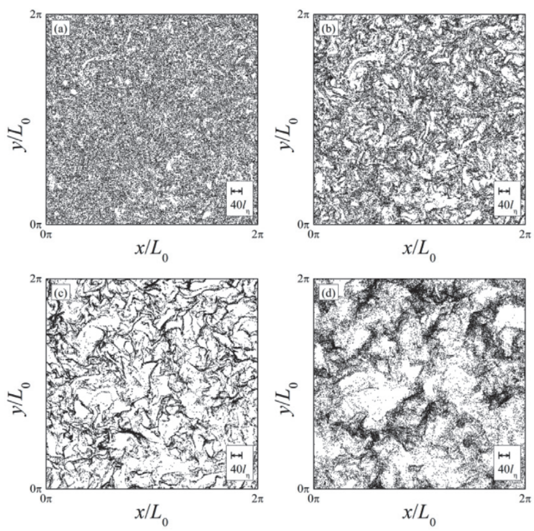


Fig. 1 Spatial distributions of droplets obtained by DNS for (a) St = 0.05, (b) 0.2, (c) 1.0 and (d) 5.0 at Re_λ = 204. Only droplets in the range $0 < z < 4l_\eta$ are drawn.

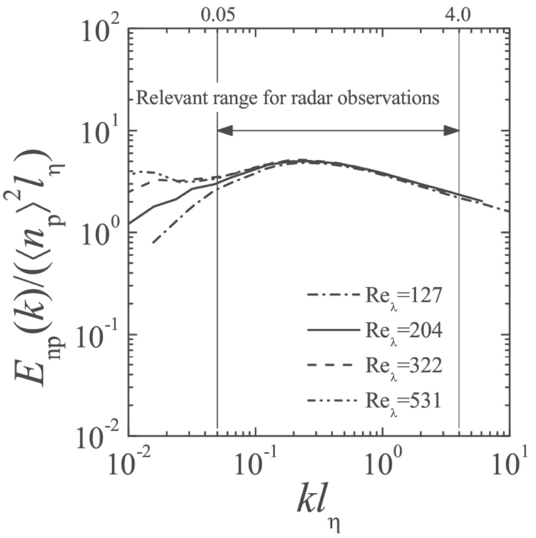


Fig. 2 Power spectra of droplet number density fluctuation obtained from DNS data for St = 1 at Re_λ = 127, 204, 322 and 531.

the number density spectrum. For Stokes numbers less than 2, the proposed model can estimate the influence of turbulence on the spectrum with an RMS error less than 1 dB when calculated over the wavenumber range relevant for radar observations. For larger Stokes number droplets, the model estimate has larger errors, but the influence of turbulence is likely negligible in typical clouds. This showed that the radar reflectivity factor model, which was developed before, is modified based on the DNS data for higher turbulent Reynolds number. As a result, the accuracy of the model is improved so that the model can estimate the radar reflectivity factor within 1 dB error [6].

3. Improvement in radiation physics for urban city planning

Improvement in radiation physics plays an important role to control atmospheric temperature in urban area. A reduction effect of temperature by planting trees in parks and the facilities site is likely to be one of the measures to decrease of heat island effect. However, the mechanism that a green tract of land has an influence on the temperature on surface is still unclear.

In this study, the temperature-reduction mechanism of green spaces is investigated. For the simulations of the heat transfer surrounding trees, the three-dimensional radiation scheme for surface-to-surface radiation is improved to consider the tree crowns as volume elements in ideal experiments (Fig. 3) By using the improved radiation scheme, we can obtain the leaf area temperature distributions inside the tree crowns more accurately. Then the heat transfer simulations for tree canopies are conducted, and analyzed the effect of the transpiration effect, tree volume and leaf area density (Fig. 4).

Furthermore, in order to validate MSSG including this radiation model, we apply the model to represent distribution of temperature and wind in Marunouchi Park Building area. As the results, the distribution of temperature and wind was comparable to observation data and validity of the model was shown (data not shown).

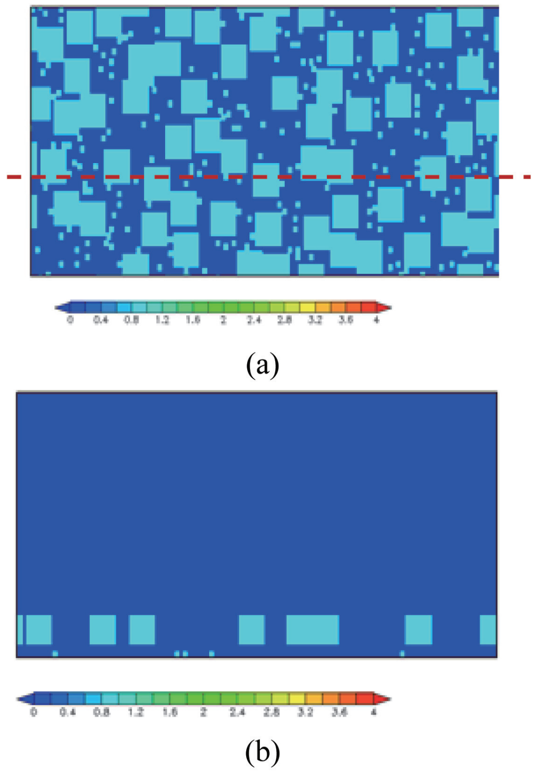


Fig. 3 Distributions of leaf area density on (a) the horizontal cross section at z=1.5m and (b) vertical cross section at y=29.5m.

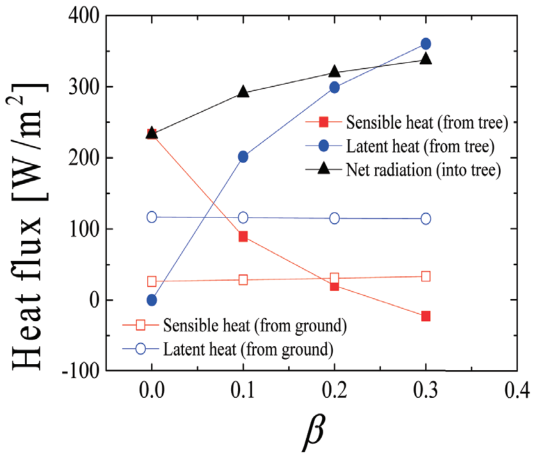


Fig. 4 Effect of the evaporation efficiency on the sensible, latent and radiative heat fluxes on the tree leaves and the ground surface.

4. Toward improvement of adaptation in urban city

4.1 Impacts of downscaling in atmosphere and ocean

Environment of mega cities located near the sea such as Tokyo is influence from condition of costal area. On the contrary, surface atmospheric forcing plays a significant role in controlling the dynamics in Tokyo Bay, in the form of surface fluxes of heat, momentum. Interaction mechanisms between the atmosphere and the ocean in urban area should not be neglected to adapt climate variability and climate change.

Previous observational and numerical studies have shown that the sea surface temperature is highly sensitive to the surface forcing including surface heating and cooling processes and the variation of the wind. Therefore, highly resolved representation in Tokyo Bay was promoted in this study.

Two sets of simulations have been carried out with low resolution of NCEP and high resolution of MSM data. Even driving by a low-resolution atmospheric forcing, the model can reveal the seasonal variation of SST reasonably. Nevertheless, refinements in resolution of atmospheric forcing are preferable in improving the model performance (Fig. 5) [7,8].

Figure 6 shows the monthly mean sea surface temperature and surface currents for the two experiments. Results show that the variable wind field has a pronounced influence to both circulation and SST in Tokyo Bay. When applying monthly mean wind, two strong anti-clockwise circulations are formed at bay head and middle bay respectively. At the same time, a strong northward coastal current is formed along east coast of the bay. However, when variably wind field is apposed, the anti-clockwise circulations are vanished, and northward coastal currents are formed along both east and west coasts. In both cases, the SST shows a high value at bay head and east coast, and a low value near bay mouth and southwest coast. When a variable wind field is adopted, the sea surface temperature decreased over the whole bay. As the results, wind distribution may significantly affect atmospheric condition in coastal area [7,8].

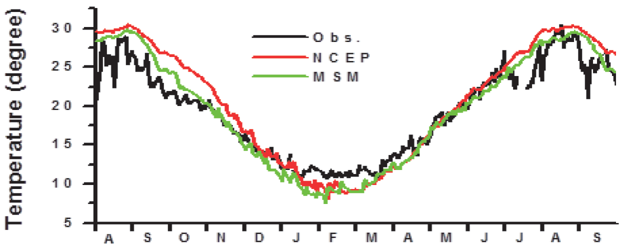


Fig. 5 Comparison of the modeled time serials of SST and the observation (Red line shows the result of the simulation using NCEP data, green line the results using MSM data).

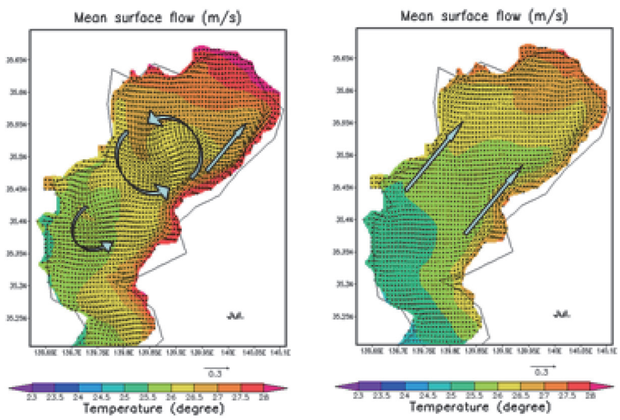


Fig. 6 Modeled SST and surface currents using monthly mean wind (left) and NCEP wind (right).

4.2 Impacts of urban building structure to heavy rain

In urban area, not only heat island phenomena but also heavy rain should be suffered for the adaptation. The mechanism of heavy rain in urban area has been still unclear, however, examinations for its prediction were tried and the result have been piled up. In reasons of of heavy rain in urban area, we focus on the roughness of urban cities. It was pointed out that roughness is becomes be larger not only the mean of building height but special deviation of buildings in urban area. Figure 7 shows special distribution of roughness for in Tokyo area in Japan considering with spatial distribution of buildings in substitution for conventional value which was calculated by land surface usage indexes. Difference of roughness for spatial distribution of buildings is shown in both Shinjuku-area and Otemchi area.

In Figure 8, simulation results of Zoshigaya-heavy rain phenomena which occurred on 5th August 2008. On the day,

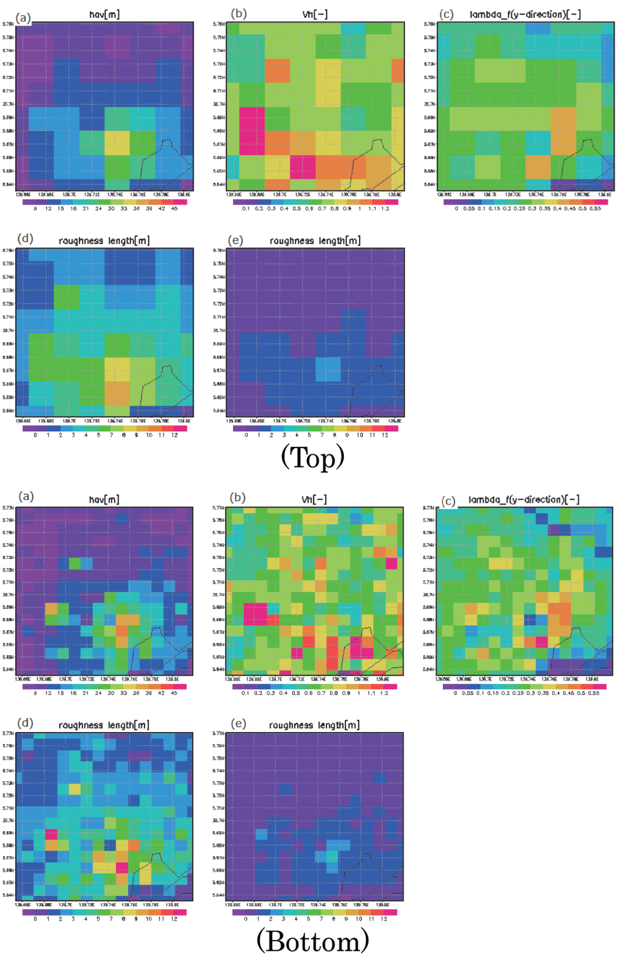
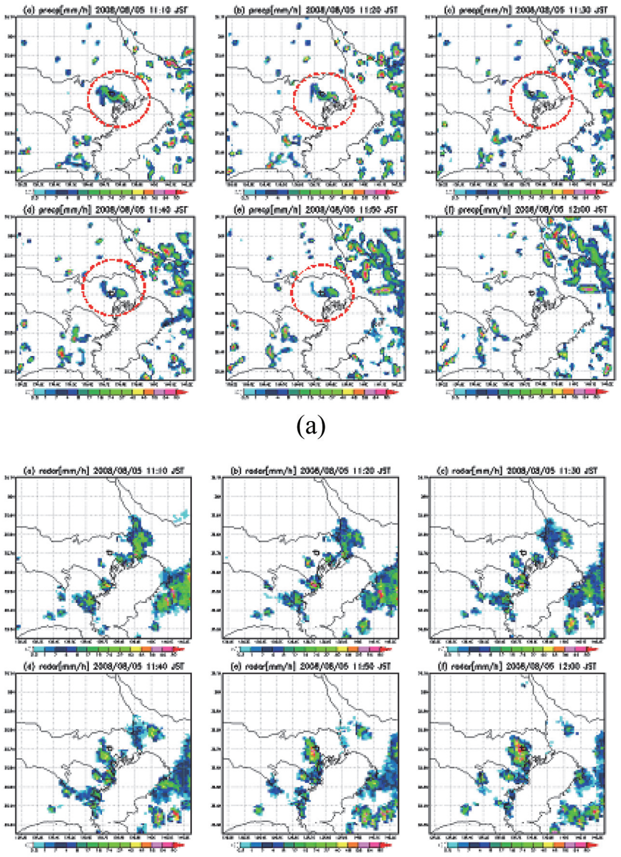


Fig. 7 Spatial distribution of roughness considering with spatial distribution of buildings in central of Totyo area. (Top) is the distribution for 2km horizontal resolution and (Bottom) shows it for 1km horizontal resolution, respectively. (a): mean building height, (b): ratio of standard deviation of the building height and the mean building height, Vh, (c): frontal area aspect ratio, λf, (d): roughness length distribution in consideration of only λf rough degree long z0, in consideration of Vh and λf, (e): z0 in consideration of λf.



(a)

(b)

Fig. 8 Spatial distribution of rain every 10 minutes from 11:00 to 12:00 on 8th August 2008. (a) shows simulation result, (b) observation data with Radar reflection strength.

simulation results with 1km horizontal resolution using MSSG shows spatial distribution of rain every 10 minutes from 11:00 to 12:00. Representation of the heavy rain has improved.

5. Future work

Environment in urban area are composed of artificial elements such as buildings or exhaust heat energy and atmospheric or oceanic physical process c elements interact complicatedly. In this report, we introduced minute three dimensional radiation model and several simulation results with the radiation model. The model and validation is necessary for consideration of future adaptation to control increasing atmospheric temperature due to accumulation of heat energy in urban area. Furthermore, it is necessary to consider that cooling effects due to wind and heat transfer from coast. Not only increasing temperature but also heavy rain in urban area is considering to adapt future climate. Previous studies indicate heavy rain may be also effect from artificial elements such as characteristic structure in urban cities. Elemental technology to reproduce severe phenomena and predict future city environment has been prepared. Using those simulation techniques, we will investigate and identify key factors to adapt in the future.

References

[1] K. Takahashi, R. Onishi, Y. Baba, S. Kida, K. Matsuda, K. Goto, and H. Fuchigami, "Challenge toward the prediction of typhoon behavior and down pour", Journal of Physics: Conference Series, Vol. 454, 012072 (2013).

[2] Keiko Takahashi, et al., "World-highest Resolution Global Atmospheric Model and Its Performance on the Earth Simulator", Proceeding of SC '11 State of the Practice Reports, Doi: 10.1145/2063348.2063376, 2011.

[3] Keiko Takahashi, et al., "Non-hydrostatic Atmospheric GCM Development and its computational performance", http://www.ecmwf.int/newsevents/meetings/workshops/2004/ high_performance_computing-11th/presentations.html, 2004.

[4] Keiko Takahashi, et al., "Non-hydrostatic atmospheric GCM development and its computational performance", Use of High Performance computing in meteorology, Walter Zwieflhofer and George Mozdzynski Eds., World Scientific, pp. 50-62, 2005.

[5] Yuya Baba and Keiko Takahashi, "Large-eddy simulation of convective boundary layer with density stratification", Journal of the Meteorological Society of Japan, Vol.89, pp.105-117, 2011.

[6] K. Matsuda, R. Onishi, M. Hirahara, R. Kurose, K. Takahashi, and S. Komori, "Influence of microscale turbulent droplet clustering on radar observations", Journal of the Atmospheric Science (accepted).

[7] L.-F. Lu, K. Takahashi, "Sensitivity of sea surface temperature in Tokyo Bay to the wind forcing", Proc. of JOS fall meeting in 2013, Sapporo, Japan, September 17-21, 2013.

[8] L.-F. Lu, K. Takahashi, "A numerical study on the response of SST in Tokyo Bay to variable wind fields", ECSA 53: Proc. Of Estuaries and coastal areas in times of intense change, Shanghai, China, October 13-17, 2013.

気候変動に適応可能な環境探索のための
マルチスケールシミュレーション

課題責任者

高橋　桂子　　海洋研究開発機構　地球シミュレータセンター

著者

高橋　桂子 *1，大西　　領 *1，馬場　雄也 *1，木田新一郎 *1，松田　景吾 *1，Li-Feng Lu*1，
Youngjin Choi*1，後藤　浩二 *2，渕上　弘光 *3

*1　海洋研究開発機構　地球シミュレータセンター

*2　NEC 株式会社

*3　NEC インフォマティックシステム株式会社

A coupled atmosphere-ocean-land model MSSG has been developed in the Earth Simulator Center, which is designed to model multi-scale interactions among the atmosphere, the ocean and the coupled system. Aiming to seamless simulation, cloud micro-physics from the both view points of the accuracy of advection computation and high computational performance and oceanic part downscaling were improved and those results are summarized. In addition, three dimensional radiation scheme was developed and its impact was shown. The trial simulation for investigate regional climate variability was performed and its result was presented in this report.

都市域の気象・気候は、大気や海洋の物理的プロセスや要素だけでなく、構造物や人工排熱などの人為的な要因の影響を受ける。将来の気候変化や変動に対する適応策を考えるには、人が実現できる具体な施策、例えば緑化や水辺の確保などを提案していく必要がある。これまで開発してきたMSSG（大気海洋結合モデルコード）は、マルチスケール現象を再現および予測するためのシームレスシミュレーションが可能である。本年度は、MSSG の放射過程モデルを 3 次元的な精緻なモデルに拡張し、樹木、建物等の放射・輻射伝熱過程をモデル化した。その結果、緑化をする場合には、中低木ではなく高木の植樹のほうが周囲の大気の低温化の効果が高いことが定量的に明らかになった（図 1）。また、都市域の大気環境は、港湾域および湾内の海洋表面温度の影響があることから、東京湾を対象に超高解像度シミュレーションを行い、風の影響について解析した。その結果、風の統計的な扱いおよびシミュレーションの解像度によって、湾内の流れが変化することから、湾内の流れおよび表面温度分布は、風と密接な関係をもって構成されていることがわかった（図 2）。さらに、将来の適応策には、近年発生頻度が高くなってきているといわれる都市の局所的な豪雨の再現性について検討を行った。その結果、都市を特徴付ける建物群は、それらの高さの平均だけでなく高さ分布も大気の状態に影響を与えていることが示唆され、これら都市の構造物が豪雨をもたらす一因になっている可能性があることがわかった（図 3）。今後は、本年度までに構築した MSSG を活用して、都市域における将来の気象および気候の予測を行い、そこに緑化ベルトや水辺の構築などの人によるアクションと施策を導入したシミュレーションを実施して、適応可能性を定量的に評価する予定である。

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

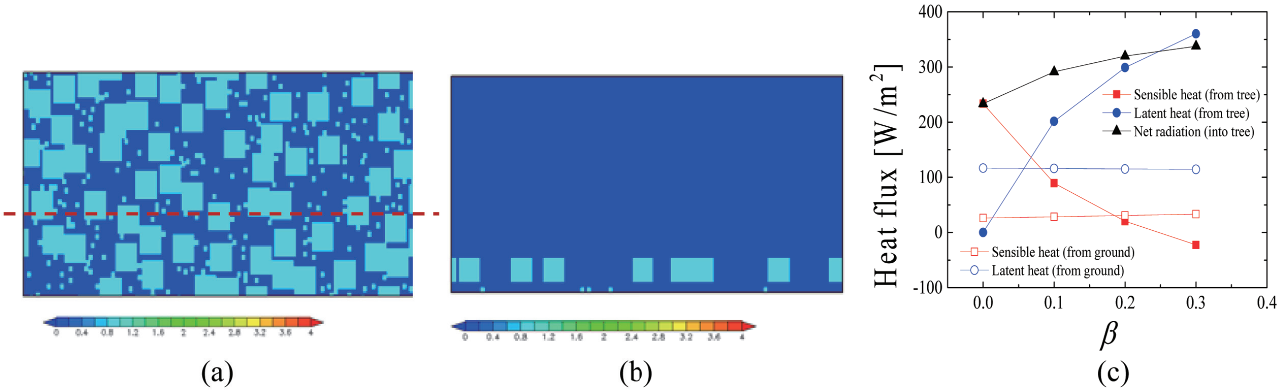


図 1　高木と中低木の 2 種類の樹木とその配置分布を設定した理想実験の概要。(a) 高さ z=1.5m の水平配置、(b) (a) 上の赤点線 y=29.5m の鉛直断面図。(c) 蒸発効率の変化による顕熱、潜熱および放射熱フラックスの変化。

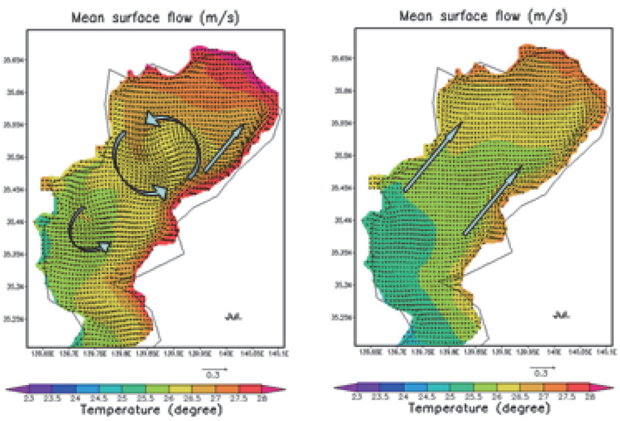


図 2　MSSG-O（MSSG の海洋大循環モデルコンポーネント）により再現された表面温度分布。左図：月平均風速を境界値として与えた場合の海表面温度分布と流れ場、右図：NCEP 風速データを与えた場合の海表面温度分布と流れ場。

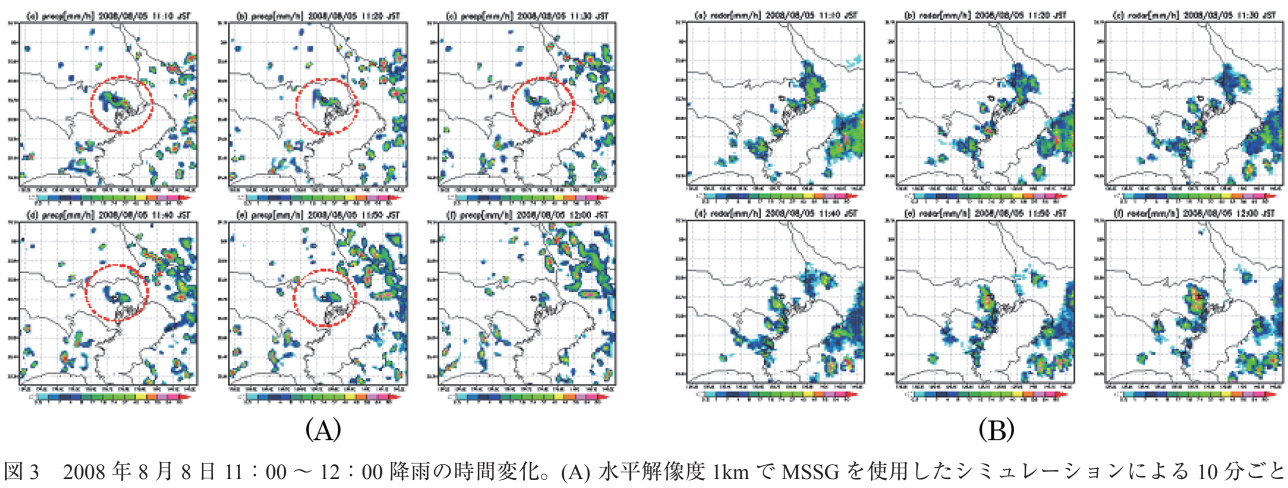


図 3　2008 年 8 月 8 日 11：00 ～ 12：00 降雨の時間変化。(A) 水平解像度 1km で MSSG を使用したシミュレーションによる 10 分ごとの積算降雨量分布。(B) レーダー反射強度から得られた 10 分ごとの降雨分布。