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Estimation for Effects of Existence of Urban on Development of Cumulonimbus Clouds Using Atmosphere-Land Coupled Model of CReSiBUC

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Synopsis

In this study, a model of CReSiBUC coupled with a cloud resolving model CReSS and a land surface processes model SiBUC was developed, and effects of existence of urban on development of cumulonimbus clouds were investigated. From a simulation for a super cell thunderstorm on 24 September 1999, rainfall amounts simulated with the CReSiBUC were confirmed to be significantly different from that with the normal CReSS. From a simulation for Nerima heavy rainfall on 21 July 1999, it was found that changes of distribution of urban and anthropogenic heat amount greatly affected the positions and amounts of rainfall.

Keywords: land atmosphere interaction, heat island, heavy rainfall

1. Introduction

Recently, in Japan, the approach on operational forecast of local weather phenomena of the horizontal scale less than 100 km has been activated. Mesoscale Spectral Model (called MSM: 10 km-resolution hydrostatic model) by Japan Meteorological Agency was begun from 2002, and such kinds of activities by private enterprise were also activated.

Meanwhile, other than the problem of a horizontal resolution of forecast models, the land surface processes are important for improvement of forecast accuracy for local weather phenomena. Destabilization and the low-level convergence with a local circulation due to the surface heating are significant triggers for generation of cumulonimbus clouds. Therefore, forecast accuracy for the part of the land surface processes relating to the surface heating is an important subject on forecast of precipitation with cumulonimbus clouds.

This study especially focuses on the cumulonimbus clouds that are generated over a plain field with big cities. Over such kind of regions, the “heat island” is considered to affect generation and development of the cumulonimbus clouds. Kobayashi (2003) investigated generation and development processes of cumulonimbus clouds in an urban area by using weather radar data. They pointed out that the processes of the cumulonimbus clouds in the urban area were different from those in mountainous regions. Fujibe (2003) suggested that the “heat island” affected generation frequency of strong rainfall events in the Tokyo metropolitan area. These suggestions with observational studies were encouraged by some numerical studies (e.g. Ohashi and Kida, 2002; Kusaka and Kimura, 2004; Rozoff et al. 2003). However, the urban effects on rainfall events have never been quantitatively discussed because of calculation accuracy of the land surface processes.

For estimation of the land effects on rainfall events, the present study develops an atmosphere-land coupled model of **CReSiBUC**. In the CReSiBUC, **CReSS**

```
sfcphy4cresibuc
            |-- soildrv
            |       |-- radiat
            |       |-- forcesfc
            |
            |-- sibucdrv
                    |-- radiat4cresibuc
                    |-- passvar2sibuc
                    |-- gim4cress
                    |-- retvar2cress
```

Fig. 1 Structure of subroutines relating to the land surface processes calculations in the CReSiBUC.

(**C**loud **Re**solving **S**torm **S**imulator: Tsuboki and Sakaibara, 2001) is adopted for atmosphere and **SiBUC** (**Si**mple **B**iosphere model including **U**rban **C**anopy: Tanaka, 2004) is adopted for land surface processes. An objective of this study is to estimate the urban effects on development of cumulonimbus clouds. For the objective, two cases of local rainfall events associated with cumulonimbus clouds are selected: the 24 September 1999 super cell thunderstorm at Toyohashi city in Aich prefecture and the 21 July 1999 Nerima heavy rainfall in Tokyo.

2. Model description

2.1 Cloud resolving atmosphere model of CReSS

The CReSS is a non-hydrostatic meteorological model developed in Hydrospheric Atmospheric Research Center, Nagoya University (Tsuboki and Sakaibara, 2001). Its source code written by the FORTRAN 90 is open to the public in the following web site.

http://www.tokyo.rist.or.jp/CReSS_Fujin/

At the present, the latest version is 2.2. All versions of the CReSS have source codes for a single CPU and multiple CPUs parallel computing. The CReSS has two significant advantages comparing to other meteorological models of MRI/NPD-NHM (Saito et al. 2001), MM5 (Dudhia et al., 1993), ARPS (Xue et al., 1995), etc. One is a high readability of the source code so that the CReSS is easy to couple with models for other processes. The other is a high calculation efficiency that satisfies a condition to use the "Earth Simulator," which is one of the fastest super computers in the world. Using the CReSS, atmospheric simulations for the broader domain with the higher resolution are possible.

2.2 Land surface processes model of SiBUC

The SiBUC is a land surface processes model developed in Water Resources Research Center, Disaster Prevention Research Institute, Kyoto University (Tanaka, 2004). The SiBUC calculates meteorological variables at the surface considering detailed processes. In the normal CReSS, the land surface processes are calculated with empirical constant values of albedo, evaporation efficiency, and roughness for simplifying calculations. To the contrary, the SiBUC calculates budgets of radiation, heat, water, and momentum while changing parameters for the surface condition. For example, for an urban area in the SiBUC, irregularity associated with buildings is considered on the basis of the urban canyon concept.

Additionally, the SiBUC adopts a "mosaic" approach. In case that a horizontal grid of the CReSS is including a number of various land use categories, values on each category are calculated and a value averaged for these is returned to the CReSS. This mosaic scheme is an effective facility especially for the domain where multiple artificial landuse categories of urban, paddy, etc. are mixed as like Japan.

2.3 Development of CReSiBUC

The CReSiBUC developed in this study is a coupled model of the CReSS and the SiBUC described in sections 2.1 and 2.2, respectively. The CReSiBUC can be used for estimating effects of urban on development of cumulonimbus clouds. The source code of the CReSS version 2.0 for a single CPU computing is used in the CReSiBUC.

Structure of subroutines relating to calculations of the land surface processes in the CReSiBUC and their features are shown in Fig. 1 and Table 1, respectively. In the normal CReSS, the land surface processes are calculated in several subroutines in the "sfcphy." On this development of the CReSiBUC, the "sfcphy4cresibuc" is made so that both "soildrv" and "sibucdrv" can be called. The "soildrv" is a subroutine for calculations of the land surface processes used in the normal CReSS. The "sibucdrv" is a subroutine including subroutines of SiBUC. Using "NAMELIST" of a standard facility of

Table 1 List of subroutines relating to the land surface processes calculations in CReSiBUC.

Subroutine	Remarks
sfcphy4cresibuc	Switching the normal scheme for surface physics in CReSS (soildrv) and SiBUC (sibucdrv).
soildrv	Controlling subroutines of the normal scheme of CReSS.
radiat	Calculating short and long radiations.
forcesfc	Calculating surface fluxes with a simple method.
sibucdrv	Controlling subroutines including SiBUC (gim4cress).
radiat4cresibuc	The same as “radiat,” but some output parameters are changed for inputting SiBUC.
passvar2sibuc	Changing array format of surface meteorological parameters for inputting SiBUC.
gim4cress	Calculating surface fluxes with SiBUC.
retvar2cress	Changing array format of surface meteorological parameters output from SiBUC.

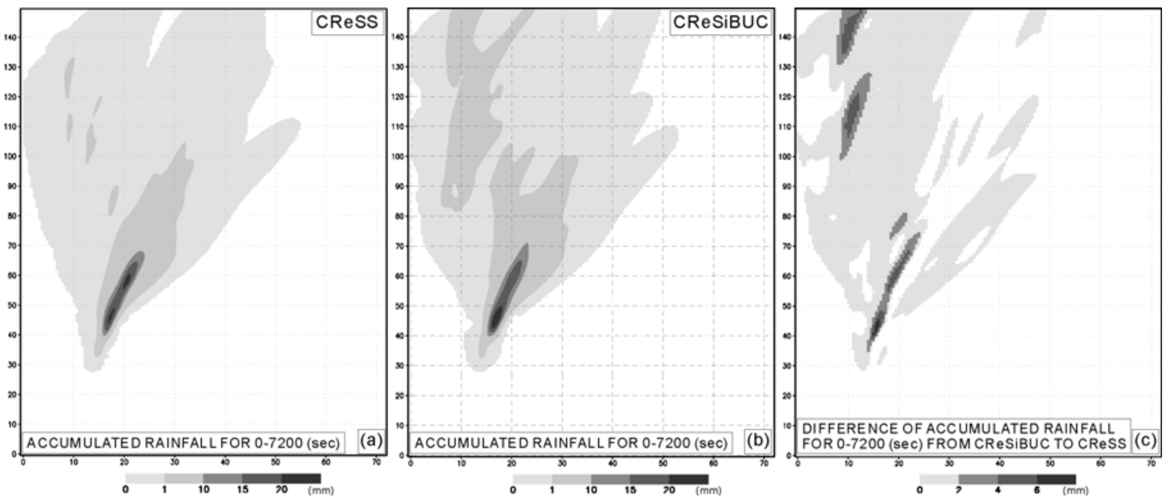

Fig. 2 Accumulated rainfall distributions simulated with (a) the normal CReSS, (b) the CReSiBUC, and (c) difference from the CReSiBUC to the CReSS.

the FORTRAN, switching of the “soildrv” and the “sibucdrv” (i.e. the normal CReSS and the CReSiBUC) can be executed without a re-compiling.

When the “sibucdrv” is called in the “sfcphy4cresibuc,” the surface fluxes is calculated by the “gim4cress” of a main routine of the SiBUC. As atmospheric boundary conditions for the land surface processes, temperature, vapor pressure, wind speed at the first layer of the atmosphere, and short and long wave radiations, and rainfall intensity are input from the part of the CReSS to the part of the SiBUC. The “gim4cress” calculates fluxes of sensible heat, latent heat, and momentum from the land surface to atmosphere. The sensible heat flux affects a source term in the time dependent equation of potential temperature at the first layer of the atmosphere. The latent heat flux affects a source term in that of vapor at the first layer of the atmosphere. The momentum flux affects a diffusion term in that of horizontal wind at the first layer of the atmosphere.

3. Importance of considering detailed processes of urban canopy

To confirm simulated rainfall difference between the normal CReSS and the CReSiBUC, simulations with the two models for a case of a super cell thunderstorm on 24 September 1999 at Toyohashi city in Aich prefecture were conducted. Tsuboki and Sakakibara (2001) have already shown that the case is well reproduced with a simple initial condition. In this simulation, a landuse of urban was uniformly assumed as the land surface in a calculation domain for verification of effects that detailed processes of urban is considered.

3.1 Simulation design

In the simulations with the CReSS and the CReSiBUC, precipitation physics of mixed-phase processes, predicting the mixing ratios of rainwater, cloud water, cloud ice, snow, and graupel, are used. The horizontal grid size is 0.5 km, and the vertical grid contains 30 levels with variable grid intervals (⊿z = 100 m near the surface and ⊿z = 500 m at the top level). The horizontal domain has 145 × 300 grid points, and big and small time steps of ⊿t = 3 seconds (for all terms except for those relating to acoustic wave) and ⊿t = 0.5 seconds (for the terms relating to acoustic wave) are used.

The initial data was uniformly given for the horizontal domain from an upper-air sounding at 09 JST on 24 September 1999 at Shionomisaki (located in the southwest of Toyohashi city). For initiating convective storm updraft, plus 4 K disturbance with a size of 20 km in diameter was given in the lowest layer in the initial field. The integration time was 7200 seconds from 09 JST on 24 September 1999.

For the whole of the domain, a landuse of urban is uniformly assumed as the land surface in both simulations with the CReSS and the CReSiBUC. In the CReSS simulation, empirical constant values of albedo, evaporation efficiency, and roughness for urban are set to 0.1, 0.1, and 0.8, respectively.

3.2 Simulation results

Simulated total rainfall for 2 hours and total rainfall difference between the CReSS and the CReSiBUC simulations are shown in Fig. 2. As in the CReSS simulation, the main features of super cell thunderstorm are well reproduced in the CReSiBUC simulation: the horizontal scale and the shape of a rainfall area are not so different between the two simulated results (Fig. 2a and b).

However, focusing on the center of the super cell (x = 10-30 km, and y = 40-70 km), the maximum value of the total rainfall simulated with the CReSiBUC is about 8 mm larger than that with the normal CReSS (Fig. 2c). Considering the fact that the total rainfall for the part of the center of the super cell is about 25 mm, the difference of 8 mm is a sufficiently large amount. This result shows the importance of the fact that the detailed land surface processes of urban is considered in short-time simulations of strong rainfall events.

4. Impact of urban effects on a heavy rainfall event

To study effects of urban on rainfall, sensitivity tests for distribution of urban and urban anthropogenic heat are conducted by the CReSiBUC. A case of the 21 July 1999 Nerima heavy rainfall is selected for the sensitivity tests. The Nerima heavy rainfall was occurred from 15 JST to 18 JST and the maximum hourly rainfall amount was 131 mm for 15-16 JST. This event was occurred in a local area of Nerima-ku in Tokyo where has a high urban centralization. The Nerima heavy rainfall is a suitable case for studying urban effects on rainfall.

4.1 Simulation design

Figure 3 shows the domains of simulations with the RSM and the CReSiBUC. In the simulations with the CReSiBUC, precipitation physics of mixed-phase processes are used. The horizontal grid size is 5 km, and the vertical grid contains 45 levels with variable grid intervals (⊿z = 100 m near the surface and ⊿z = 500 m at the top level). The horizontal domain has 100 × 100 grid points, and big and small time steps of ⊿t = 10 seconds and ⊿t = 5 seconds are used.

The initial and lateral boundary data were provided from output produced by the Regional

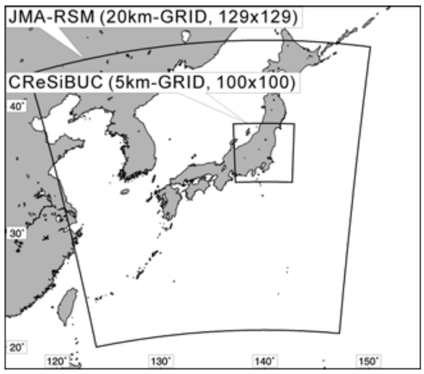

Fig. 3 Model domains of a 20 km-resolution hydrostatic model (marked as JMA-RSM), and a 5 km-resolution non-hydrostatic model (marked as CReSiBUC).

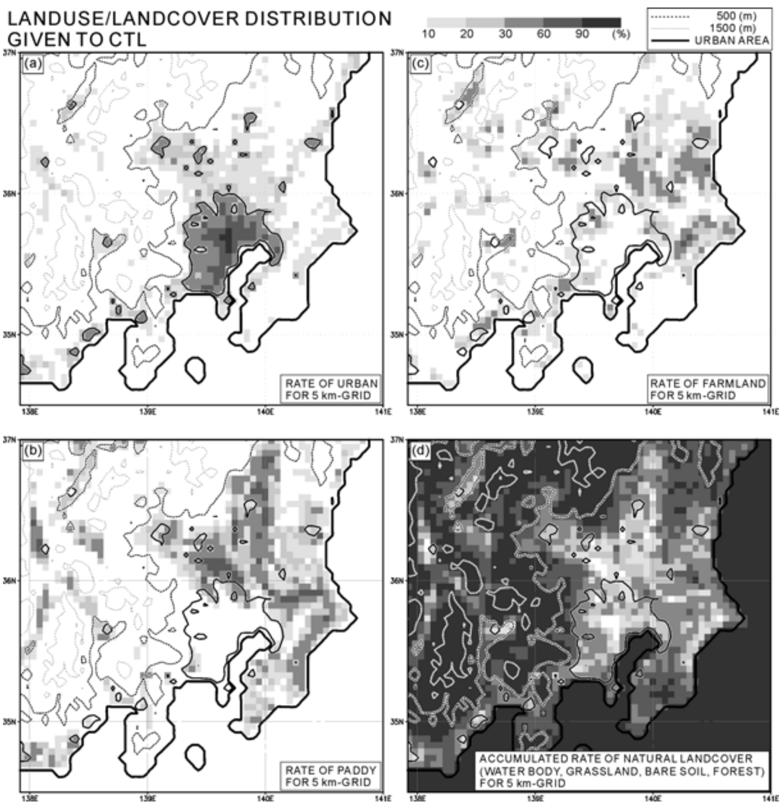

Fig. 4 Landuse/landcover distribution given to the CTL simulation (only for an analysis domain). Rate of (a) urban, (b) paddy, and (c) farmland, and accumulated rate of natural landcover (water body, grassland, bare soil, and forest) for each 5 km-grid of the CReSiBUC are shaded. Dashed thick and thin lines indicate terrain heights of 500 m and 1500 m, respectively. The “urban area” where the rate of urban is over 30 % is surrounded by the solid line.

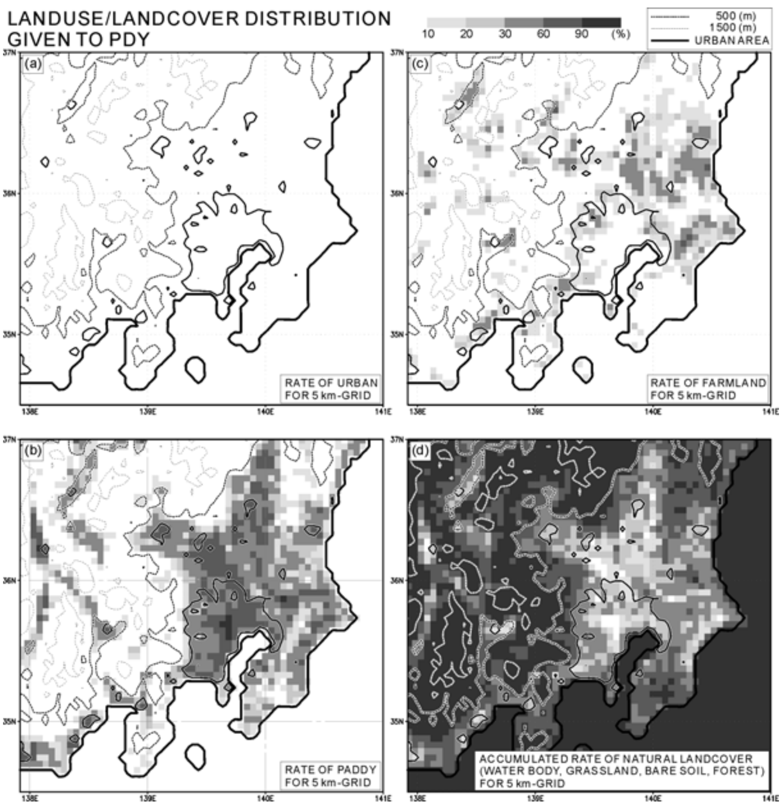

Fig. 5 The same as Fig. 4, but given to the PDY simulation.

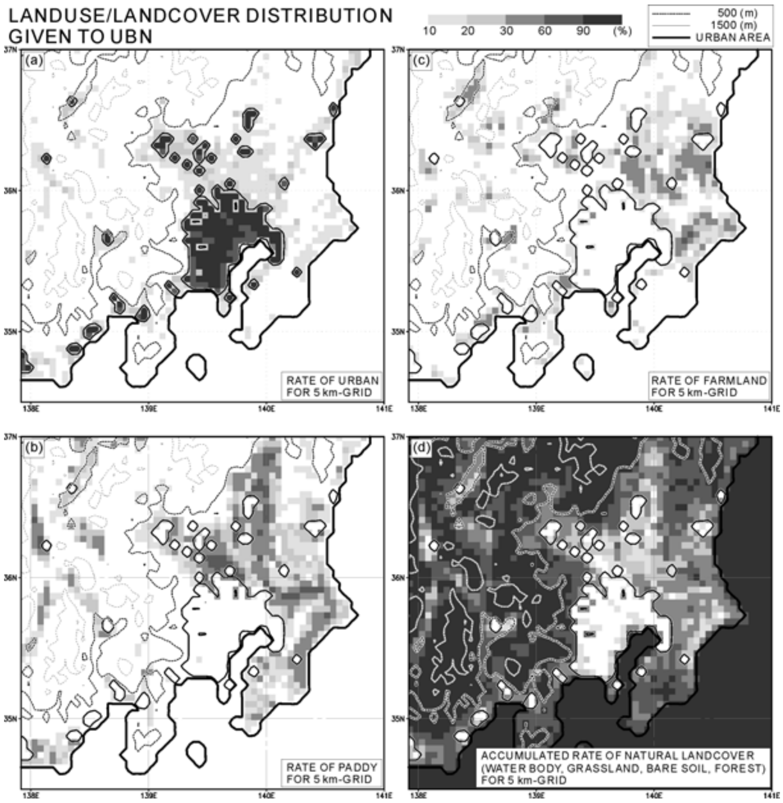

Fig. 6 The same as Fig. 4, but given to the UBN simulation.

Spectral Model (RSM: a hydrostatic model used operationally in Japan Meteorological Agency, referred in Segami et al., 1987). The horizontal resolution of the RSM is about 20 km and the horizontal domain has 129 × 129 grid points. The CReSiBUC simulation was one-way nested within the RSM started at 09 JST on 21 July 1999. The integration time of the CReSiBUC simulation was 12 hours from 09 JST on 21 July 1999, and lateral boundary data was given every 1 hour.

To study effects of existence of urban on the generation of the Nerima heavy rainfall, simulations called CTL, PDY, and UBN (abbreviations of control, paddy, and urban, respectively) are conducted using the following three patterns of the landuse/landcover

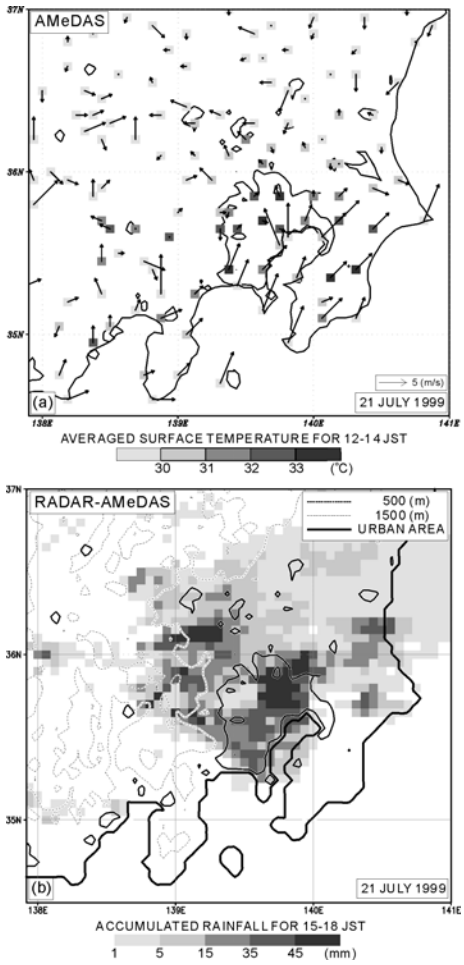

Fig. 7 (a) Averaged surface temperature for 12-14 JST with the AMeDAS, and (b) accumulated rainfall for 15-18 JST with the Radar-AMeDAS on 21 July 1999. Dashed thick and thin lines indicate terrain heights of 500 m and 1500 m, respectively. The "urban area" where the rate of urban is over 30 % is surrounded by the solid line.

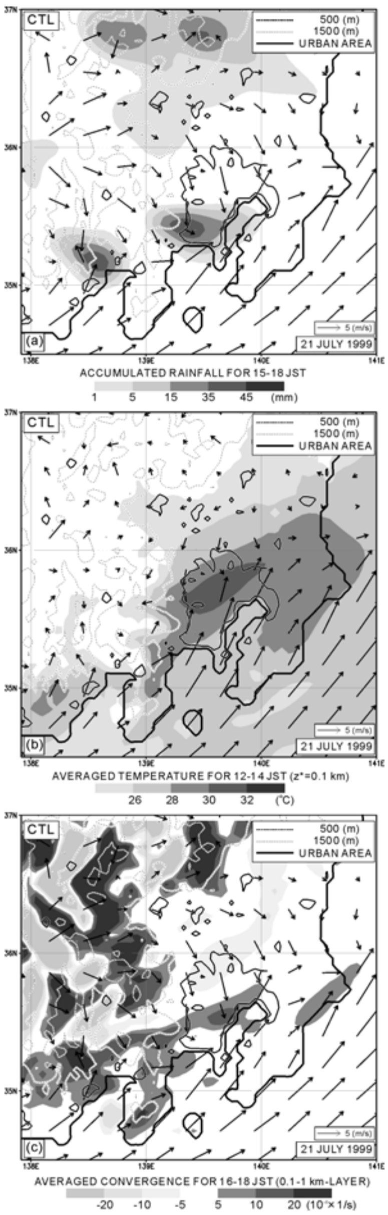

Fig. 8 Simulated results with the CTL of (a) accumulated rainfall for 15-18 JST, (b) averaged temperature at 0.1 km for 12-14 JST, and (c) averaged convergence accumulated in the 0.1-1 km-layer for 16-18 JST. Dashed thick and thin lines indicate terrain heights of 500 m and 1500 m, respectively. The "urban area" where the rate of urban is over 30 % is surrounded by solid line. Vectors of winds at a height of 0.1 km are shown in all panels.

distributions. One is the actual distribution as shown in Fig. 4. The second one is the distribution in which urban is replaced to paddy as shown in Fig. 5. The third one is the distribution in which urban near Tokyo is increased as shown in Fig. 6. In this study, the area where the rate of urban per 5 km square unit is over 30 % is expediently defined as "urban area" (surrounded by the solid line in all figures after Fig. 4). In the distribution data for the UBN, all landuse/landcover categories except for water body are replaced to urban only in the "urban area."

In addition, to consider effects of anthropogenic heat in urban, a simulation that the anthropogenic heat of 400 W/m^{-2} is given (hereafter called AH400) is conducted. The anthropogenic heat is an artificial heating the lower atmosphere due to cooling equipments, cars, etc. According to distribution data of urban anthropogenic heat in Tokyo (Ichinose et al., 1994), a heat amount of about 300-400 W/m^{-2} is discharged in Tokyo during a summer season. Although the realistic anthropogenic heat amount is changed in time, the constant amount of 400 W/m^{-2} is assumed in the AH400.

4.2 Characteristics of landuse/landcover distribution of model domain

The calculation domain with the CReSiBUC has a significant characteristic of landuse/landcover distribution, that is, the area of artificial landuse categories of urban, paddy, and farmland are relatively broad (Fig. 4a, b, and c). Generally, the natural landcover of water body (river, lake, and sea), grassland, bare soil, and forest is predominantly distributed over the Japan islands. In the calculation area, the area where the rate of the natural landcover exceeds 60% is predominantly distributed (Fig. 4d). However, around the Bay of Tokyo, the area where the rate of the urban exceeds 30% (defined as the "urban area" in section 4.1) has the width of about 100 km, and the area where the accumulated rate of paddy and farmland is about 20-30 % is expanded in the northern and eastern sides of the "urban area." The Kanto district is a region that has a remarkable contrast of landuse/landcover distribution in the west-east direction. Therefore, the surface heating difference between the western and eastern areas could tend to be significant, and local circulations could be easy to develop.

Under this condition, the "urban area" where the surface heating is quite large due to the "heat island" effect is located in the center of the Kanto plain. It is considered that the low-level winds could be easy to converge at the "urban area" where tends to be the local area of high temperature and low pressure.

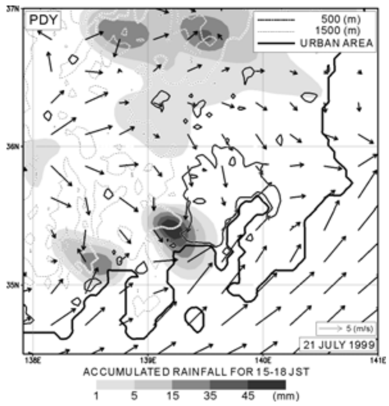

Fig. 9 15-18 JST accumulated rainfall simulated with the PDY. Vectors of winds at a height of 0.1 km are shown.

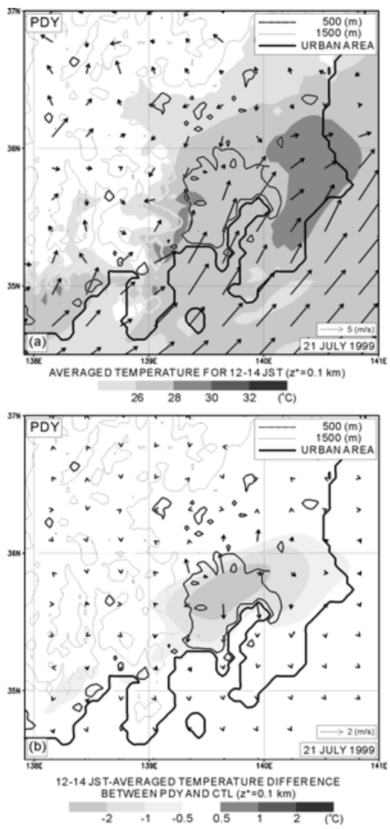

Fig. 10 (a) 12-14 JST averaged temperature at a height of 0.1 km simulated with the PDY, and (b) temperature difference between the PDY and the CTL. Vectors in (a) indicate winds, and in (b) indicate wind difference between the PDY and the CTL at a height of 0.1 km.

4.3 Observational characteristics over the Kanto Plain on 21 July 1999

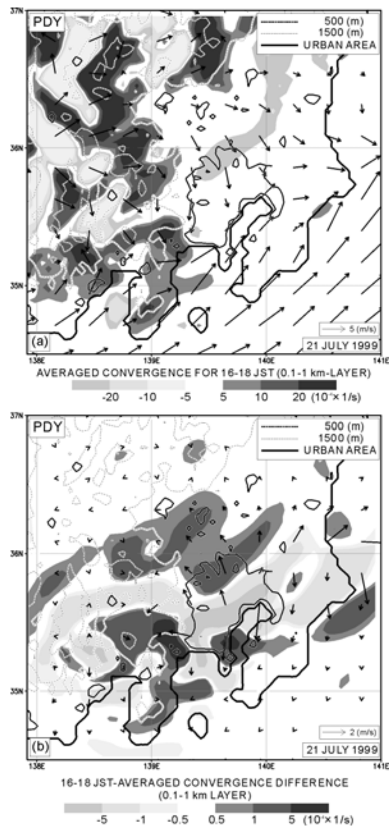

Fig. 11 (a) 16-18 JST averaged convergence in the 0.1-1 km layer simulated with the PDY, and (b) convergence difference between the PDY and the CTL. Vectors in (a) indicate winds, and in (b) indicate wind difference between the PDY and the CTL at a height of 0.1 km.

Averaged surface temperature and wind with the AMeDAS (Automated Meteorological Data Acquisition System) for 12-14 JST and accumulated rainfall with the Radar-AMeDAS for 15-18 JST are shown in Fig. 7. Before the generation of the Nerima heavy rainfall, the Kanto district was clear sky, and the feature of the "heat island" was clearly shown in the distribution of the surface temperature. The temperature over 33 degree C is observed in the "urban area," and that less than 31 degree C is outside of the "urban area" (Fig. 7a). The surface winds in and around the "urban area" tend to converge in the center of the "urban area."

The strong rainfall exceeding 45 mm associated with the Nerima heavy rainfall is locally induced in the area of about 50 km square (Fig. 7b). The position of the strong rainfall corresponds to that of the area of high temperature and convergence of winds. From these observational evidences, it is suggested that the Nerima

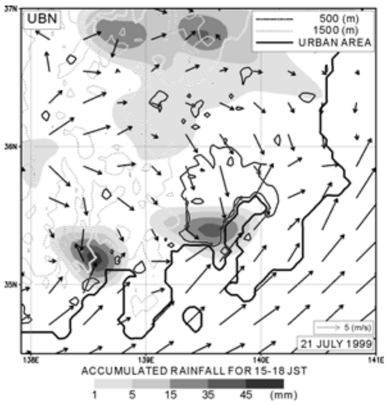

Fig. 12 15-18 JST accumulated rainfall simulated with the UBN. Vectors of winds at a height of 0.1 km are shown.

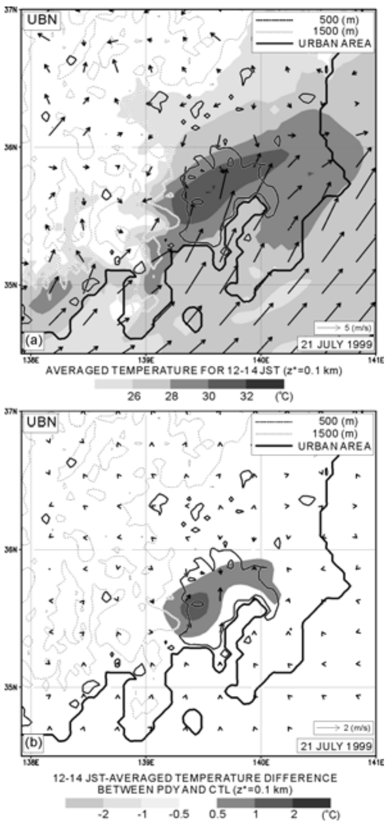

Fig. 13 (a) 12-14 JST averaged temperature at a height of 0.1 km simulated with the UBN, and (b) temperature difference between the UBN and the CTL. Vectors in (a) indicate winds, and in (b) indicate wind difference between the UBN and the CTL at a height of 0.1 km.

heavy rainfall is strongly affected by the urban.

4.4 Effects of distribution of urban on rainfall

Comparing to the observation results in Fig. 7, the

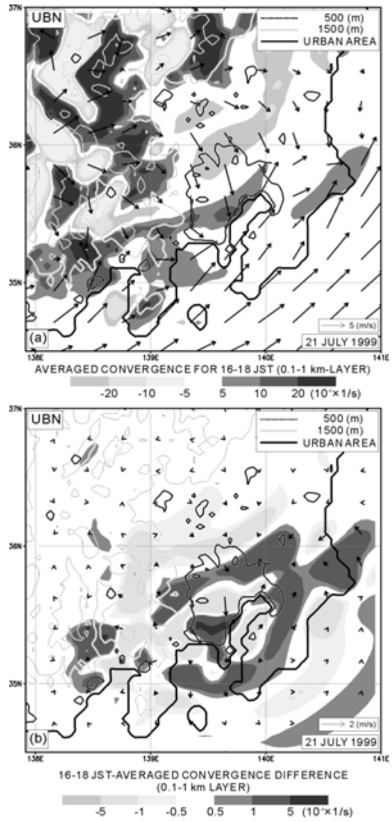

Fig. 14 (a) 16-18 JST averaged convergence in the 0.1-1 km layer simulated with the UBN, and (b) convergence difference between the UBN and the CTL. Vectors in (a) indicate winds, and in (b) indicate wind difference between the UBN and the CTL at a height of 0.1 km.

CTL simulation well reproduced the main features of the Nerima heavy rainfall as in Fig. 8. A local strong rainfall over 35 mm is located in the "urban area," although its position is slightly shifted in the southwest from that of the actual the Nerima heavy rainfall. This shift could result from accuracy of the initial and lateral boundary data from the RSM. A high temperature area (> 30 degree C) is seen in the distribution of temperature at a height of 0.1 km as shown in the actual observation. The position of convergence in the 0.1-1 km layer exceeding 10×10^{-4} 1/s is well corresponded to the high temperature area.

Rainfall distribution with the PDY simulation is shown in Fig. 9. Comparing to the CTL, a strong rainfall area is shifted further west. Figure 10 shows fields of temperature and temperature difference between the PDY and the CTL. In the PDY, a high temperature area in the "urban area" is not seen, that is, the "heat island" phenomenon is not occurred (Fig. 10a). Around the area where is the temperature decrease exceeding 2 degree C, winds are changed to the direction to the outside of the "urban area" (Fig. 10b). Figure 11 shows fields of convergence and convergence difference. A remarkable convergence

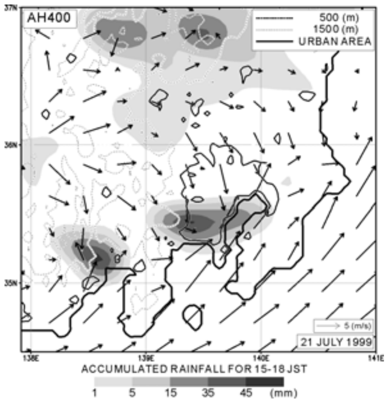

Fig. 15 15-18 JST accumulated rainfall simulated with the AH400. Vectors of winds at a height of 0.1 km are shown.

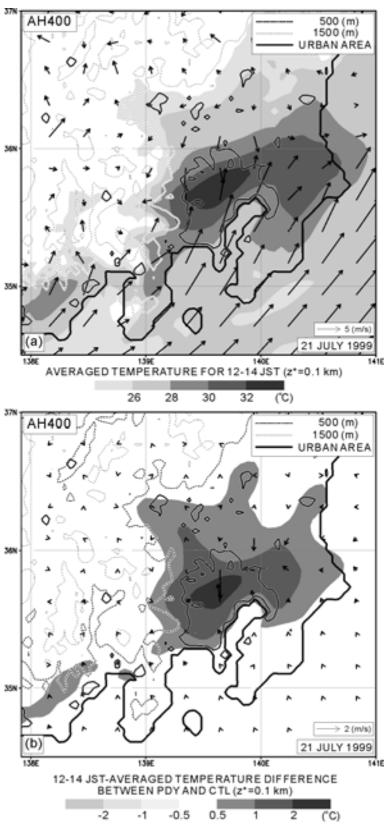

Fig. 16 (a) 12-14 JST averaged temperature at a height of 0.1 km simulated with the AH400, and (b) temperature difference between the AH400 and the CTL. Vectors in (a) indicate winds, and in (b) indicate wind difference between the AH400 and the CTL at a height of 0.1 km.

zone is not seen in the "urban area" (Fig. 11a). Comparing to the CTL, the convergence in the "urban area" is decreased by 5 × 10^{-4} 1/s, meanwhile the convergence in a mountainous region in the west is found to be increased.

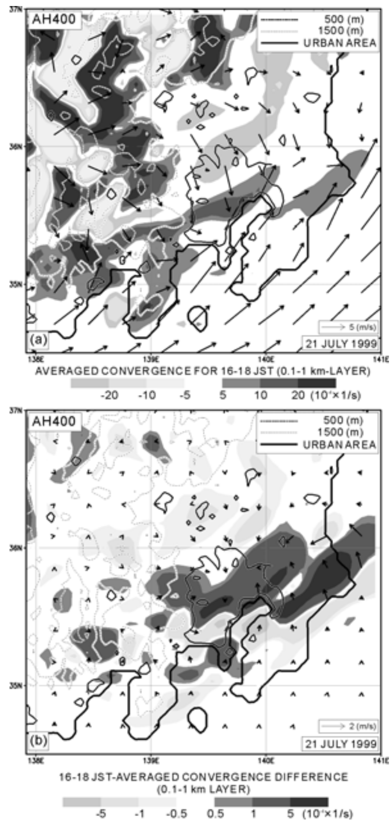

Fig. 17 (a) 16-18 JST averaged convergence in the 0.1-1 km layer simulated with the AH400, and (b) convergence difference between the AH400 and the CTL. Vectors in (a) indicate winds, and in (b) indicate wind difference between the AH400 and the CTL at a height of 0.1 km.

Rainfall distribution with the UBN simulation is shown in Fig. 12. Comparing to the CTL, a strong rainfall area is shifted further east. Figure 13 shows fields of temperature and temperature difference between the UBN and the CTL. In the UBN, a high temperature area (> 30 degree C) in the "urban area" is extended, that is, the feature of the "heat island" in the UBN is more significant than that in the CTL (Fig. 13a). Around the area where is the temperature increase exceeding 1 degree C, the winds are changed to the direction toward the "urban area" (Fig. 13b). Figure 14 shows fields of convergence and convergence difference. A remarkable convergence zone is seen in the "urban area" as in the CTL (Fig. 14a). Comparing to the CTL, the convergence in the "urban area" is increased by over 5 × 10^{-4} 1/s (Fig. 14b).

It can be explained that the position of the generation of precipitation clouds is shifted resulting from the fact that the surface heating with the "heat island" is changed due to with or without of urban, and concentration of urban. From these results of the PDY and the UBN, it is considered that the existence of urban changes the low-level convergence through the effects of the "heat island," and significantly affects the position of the generation of a heavy rainfall.

4.5 Effects of anthropogenic heat on rainfall

Rainfall distribution with the AH400 simulation is shown in Fig. 15. Comparing to the CTL, a strong rainfall area is extended in the west-east direction. An increase of rainfall amount of 10 mm in the maximum was seen in the "urban area." Figure 16 shows fields of temperature and temperature difference between the AH400 and the CTL. In the AH400, a high temperature area (> 32 degree C) in the "urban area" is seen, and the feature of the "heat island" in the AH400 is more significant than that in the UBN (Fig. 16a). Around the area where is the temperature increase exceeding 2 degree C, winds are changed to the direction toward the "urban area" (Fig. 16b). Figure 17 shows fields of convergence and convergence difference. A remarkable convergence zone is seen in the "urban area" as in the CTL (Fig. 17a). Comparing to the UBN, the area of the increase of 1×10^{-4} 1/s from the CTL is extended (Fig. 17b).

This result cautions about the following scenario. Buildings will become higher and higher, and anthropogenic heat per unit area associated with cooling equipments will increase more and more. It is suggested that growing of such kind of human-induced effects affects intensity and frequency of heavy rainfall disasters in urban areas.

5. Conclusions

In this study, a model of CReSiBUC coupled with a cloud resolving model CReSS and a land surface processes model SiBUC was developed. In a simulation for a super cell thunderstorm on 24 September 1999, rainfall amounts simulated with the normal CReSS and the CReSiBUC were significantly different. From this result, the fact that the detailed land surface processes is considered is confirmed to be very important for rainfall simulations with a mesoscale model. In a simulation for Nerima heavy rainfall on 21 Jul. 1999, it was found that changes of distribution of urban affected the position of a rainfall area in association with the "heat island" effect. In addition, it was clarified that anthropogenic heat amount greatly affected the horizontal scale of a rainfall area and the quantitative rainfall amount.

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大気・陸面結合モデルCReSiBUCを用いた積乱雲発達に対する都市の存在の影響評価

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要旨
本研究では、雲解像モデルCReSSと陸面過程モデルSiBUCを結合したCReSiBUCを開発し、都市の存在が積乱雲発達に与える影響を調べた。1999年9月24日のスーパーセルの実験では、標準のCReSSとCReSiBUCでそれぞれ再現される降水量に顕著な差が生じることを示した。1999年7月21日の練馬豪雨の実験では、都市の分布と人口排熱量の変化が降水の位置や量に大きな影響を持つことが分かった。

キーワード: 大気・陸面相互作用、ヒートアイランド、豪雨

大気・陸面結合モデル CReSiBUC による積乱雲発達に対する都市の存在の影響評価

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１．はじめに

本研究では、名古屋大学で開発された雲解像モデル CReSS と京都大学で開発された陸面過程モデル SiBUC を結合した CReSiBUC の開発を行った。この CReSiBUC を用いることによって、従来の数値モデルでは困難であった積乱雲の発生・発達における陸面過程の影響評価を行うことを本研究の目的とする。ここでは、陸面過程が発達に重要であると思われる積乱雲を 2 事例選出し、都市の存在が降水にもたらす影響に着目して解析を行った。

２．都市の陸面過程を詳細に扱うことによる効果

1999 年 9 月 24 日の 11JST から 12JST にかけての愛知県豊橋市において、スーパーセル型の積乱雲が発達した。この対象事例を再現する際に、簡便な陸面モデルが採用されている標準の CReSS と CReSiBUC でそれぞれ実験を行った。二つの実験結果を比較すると、CReSS に比べて CReSiBUC では、スーパーセルの中心部において降水量が 1 時間積算値で最大 7 mm 増加していた(図示せず)。この結果は、短時間降雨予測においても、都市での陸面過程を詳細に考慮することによる効果が小さくないことを示している。

３．都市の存在が積乱雲発達に与える影響

1999 年 7 月 21 日の東京都練馬区において練馬豪雨と呼ばれる豪雨災害があり、一時間最大降水量で 131 mm を記録した。この練馬豪雨を水平解像度 5 km の CReSiBUC で再現する際に、実際の土地利用分布データを与えた実験(CTL)、都市を水田に置き換えた実験(PDY)、都市をより過密にした実験(UBN)、人工排熱量 400W/m^{-2} を与えた実験(AHD、他では 0W/m^{-2} としている)を行った。CTL(図 1a)では、レーダーアメダス観測雨量(図示せず)と比較して、概ね練馬豪雨の特徴を再現した。

練馬豪雨がもたらされた 1999 年 7 月 21 日 15JST から 18JST までの 3 時間積算降雨量分布を図１に示す。CTL に比べて PDY および UBN の結果(図 1b と c)では、降水域の位置が西側、東側にそれぞれずれている。また、AHD(図 1d)では、CTL と比べて、降水域の水平規模が拡大し、定量的にも 10 mm 程度の雨量の増加が見られた。

４．結論

本研究では、雲解像モデル CReSS と陸面過程モデル SiBUC を結合した CReSiBUC の開発を行った。1999 年 9 月 24 日のスーパーセルの理想実験では、地表面を一様な草地、都市と仮定した場合、CReSS と CReSiBUC で再現される降水量に顕著な差が生じることを示した。この結果から都市の陸面過程を考慮することは、短時間の降水予測においても高い重要性を持つことが示唆された。1999 年 7 月 21 日の練馬豪雨の再現実験では、都市の分布の変化が降水域の形成位置に対して影響を及ぼすことが明らかにされた。さらに、都市における人工排熱量が、降水域の水平・定量規模を大きくする影響を持つことが分かった。

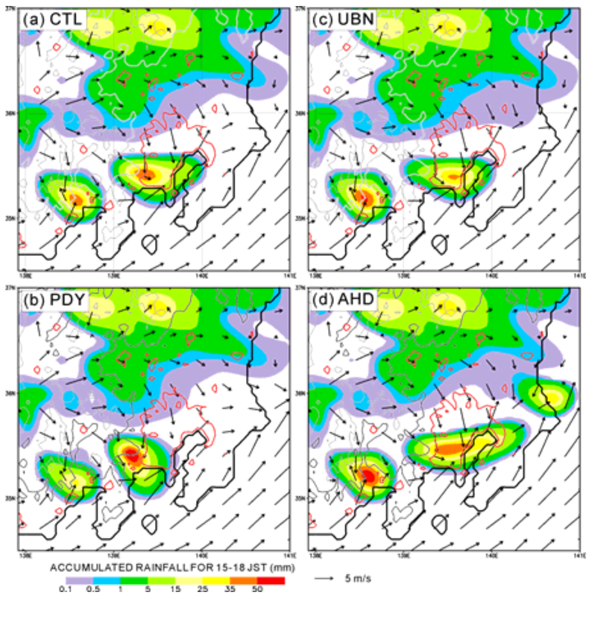

図１：CReSiBUC で計算された (a)CTL、(b)PDY、(c)UBN、(d)AHD による３時間積算降水量分布。赤線で囲まれた領域は、土地利用分布データにおいて感度実験の際にデータ操作を行った都市領域を示す。