Observational Study and Numerical Prediction Experiments on Wet-Bulb Globe Temperature in Tajimi, Gifu Prefecture: Consideration of Uncertainty with a Physics Parameterization Scheme and Horizontal Resolution of the Weather Research and Forecasting Model

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Observational Study and Numerical Prediction Experiments on Wet-Bulb Globe Temperature in Tajimi, Gifu Prefecture: Consideration of Uncertainty with a Physics Parameterization Scheme and Horizontal Resolution of the Weather Research and Forecasting Model

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As part of research on the actual conditions of the thermal environment surrounding the city of Tajimi, Gifu prefecture, and the city of Kasugai, Aichi prefecture, the surface air temperature and wet-bulb globe temperature (WBGT) were investigated by observation at these locations on clear-sky days in August 2010. Numerical prediction experiments on the WBGT were performed to confirm the utility of the Weather Research and Forecasting (WRF) model. Sensitivity experiments utilizing physics parameterization schemes and horizontal resolution of the WRF model were conducted to confirm the predicted WBGT. The results showed that the maximum sensitivity with the parameterization scheme was 8.4°C for the daytime average, and especially, the simple thermal diffusion surface (SLAB) scheme caused an overestimation of 6.8°C. On the other hand, the maximum sensitivity with horizontal resolution was 0.5°C, which is much less than that with the parameterization scheme.

Key words: extreme high surface air temperature, wet-bulb globe temperature (WBGT), numerical prediction experiment, Tajimi
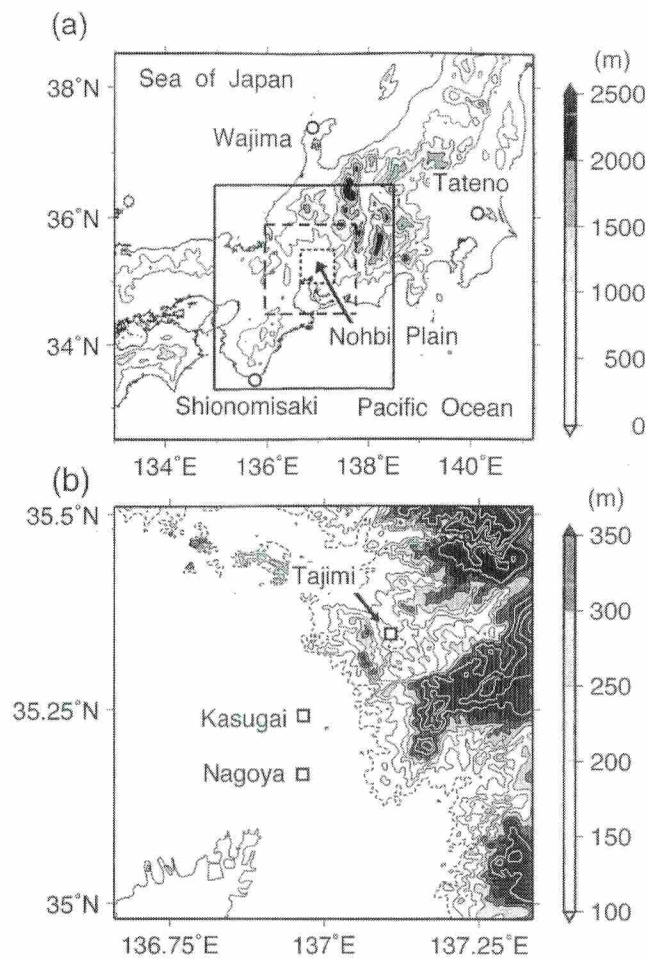
Fig. 1   Domain for numerical experiments

(a) Map of the Chubu area and (b) child domain (domain 3, Tajimi-Kasugai-Nagoya region). The solid square represents the parent domain (domain 1, Kinki-Chubu area). The dashed and dotted squares represent child domains (domain 2, Nohbi plain area; domain 3, Tajimi-Kasugai-Nagoya region). The solid lines correspond to elevation with contour intervals of (a) 500 m and (b) 50 m. The dashed line of (b) corresponds to elevation with contour intervals of 100 m.
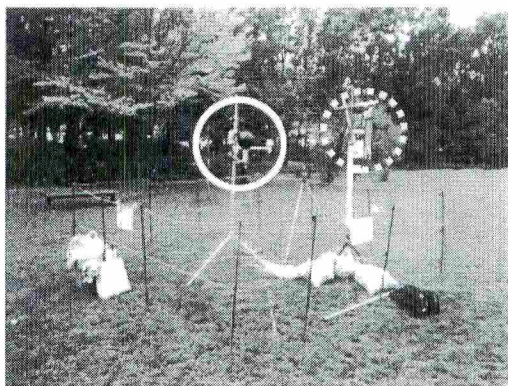

Fig. 3   Installation environment in Taihei Park in Tajimi. The dashed circle represents Assman's aspiration psychometer, and the solid circle globe thermometer.
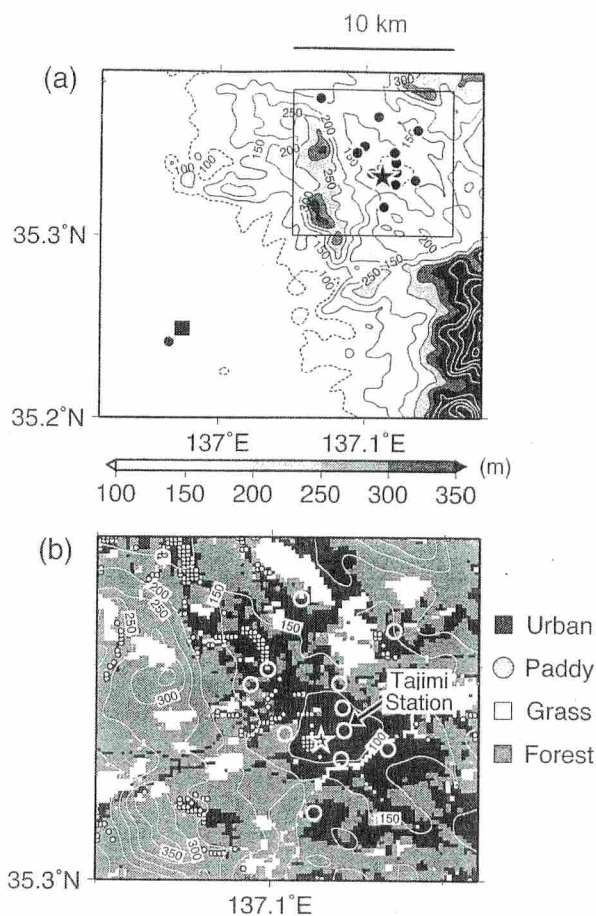
Fig. 2   Location of observation sites in (a) Tajimi and Kasugai and (b) Tajimi (extended figure)
The star (★) and square (■) represent Taihei Park in Tajimi and Harumi Park in Kasugai, respectively. WBGT (globe temperature, wet-bulb temperature, and dry-bulb temperature) was observed at these sites. The circles (● or ○) indicate observation sites for temperature alone. The thin solid lines represent elevation with contour intervals of 50 m. The dashed line of (a) corresponds to elevation with contour intervals of 100 m. The thick solid square in (a) indicates the area of (b). The shading in (b) indicates land-use categories.
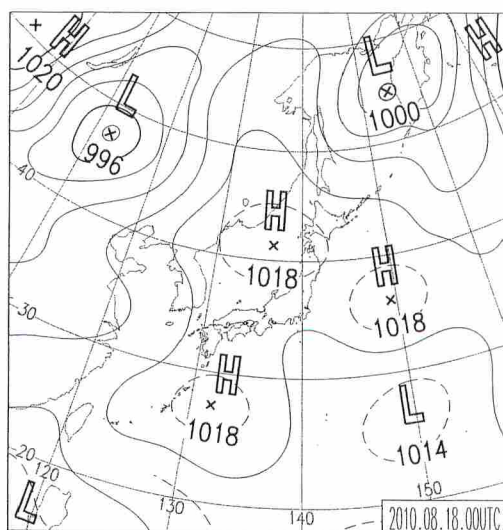

Fig. 4   Surface weather chart at 09:00 Japan Standard Time (JST) on 18 August 2010
The solid line indicates isobars per 4 hPa. Taken from Japan Meteorological Agency Weather Charts of August 2010 (CD-R).
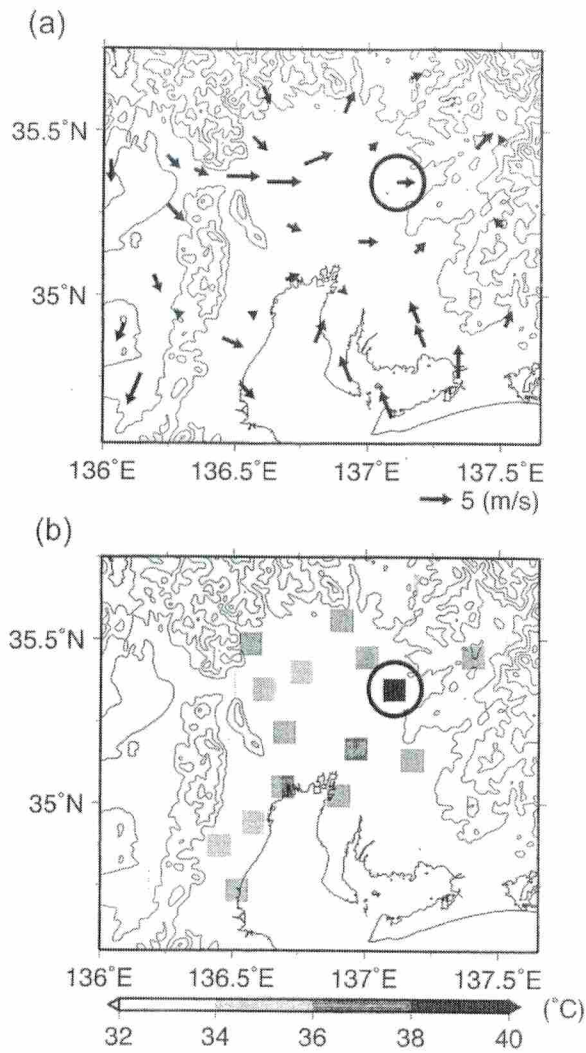
(a)

(b)

Fig. 5　(a) Surface wind field (vector) and (b) surface air temperature (shading) observed by AMeDAS at 14:00 JST on August 18, 2010
The solid lines indicate elevation with contour intervals of 300 m. The circle represents Tajimi Station.
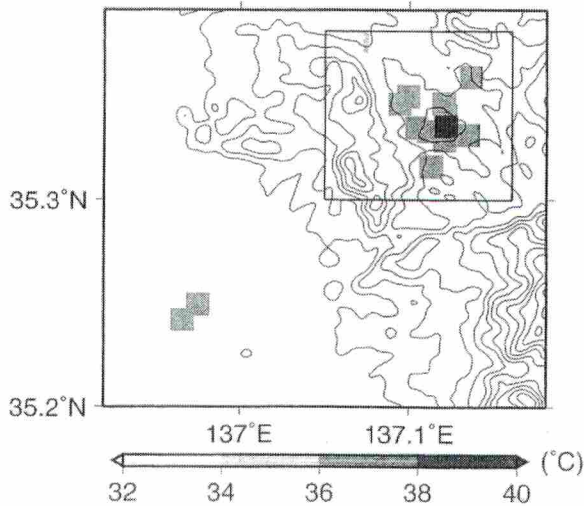

Fig. 6　Surface air temperature (shading) observed at 14:00 JST on 18 August 2010 in Tajimi and Kasugai
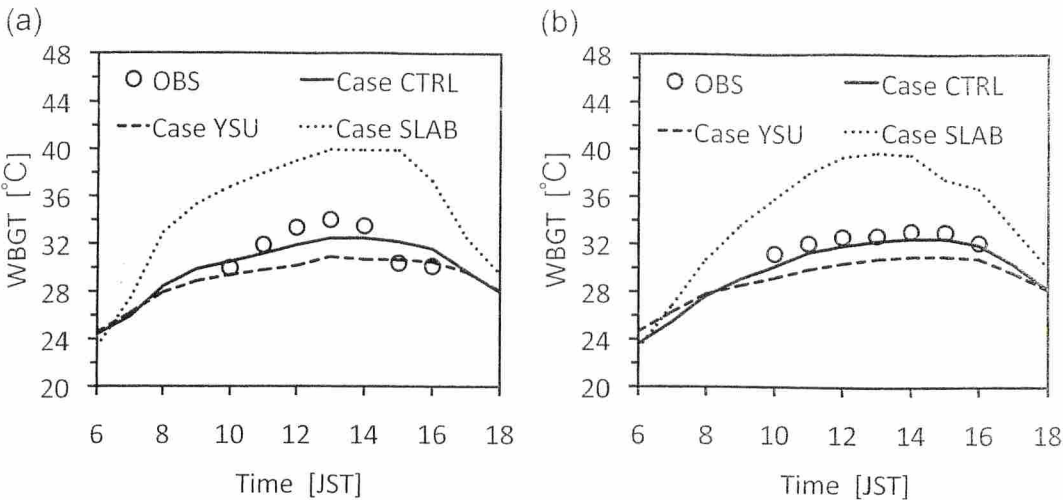The thin solid lines represent elevation with contour intervals of 50 m.

(a)

(b)

Fig. 7 Diurnal variation of WBGT from 06:00 to 18:00 JST on August 18, 2010 in (a) Taihei Park in Tajimi and (b) Harumi Park in Kasugai

The circles represent observed results, the solid line the control (CTRL) results, the dashed line the YSU results, and the dotted line the SLAB results.

Table 1 (a) Daily maximum WBGT and (b) daytime (10:00–16:00 JST) average WBGT observed on August 18, 2010 in Taihei Park in Tajimi and Harumi Park in Kasugai

(a)

Park	Time [JST]	WBGT [°C]	$0.7T_w$ [°C]	$0.2T_g$ [°C]	$0.1T_d$ [°C]
Taihei	13	34.0	18.1	12.2	3.7
Harumi	14	33.1	18.6	10.7	3.8

(b)

Park	WBGT [°C]	$0.7T_w$ [°C]	$0.2T_g$ [°C]	$0.1T_d$ [°C]
Taihei	31.9	18.1	10.3	3.5
Harumi	32.5	18.4	10.4	3.7

Table 2 Specifications of the WRF model used in the present numerical experiments

	Region 1	Region 2	Region 3
Domain	Fig. 1(a)	Fig. 1(a)	Fig. 1(b)
Horizontal Resolution [km]	2.7	0.9	0.3
Grid Number (x, y, z)	120, 130, 50	181, 181, 50	199, 199, 50
Integral Time [hour]	33 (12 JST 17th to 18th August 2010)		
Initial and Boundary Conditions (Atmosphere)	JMA MSM	—	—
— (Land)	NCEP Final Analysis (FNL)	—	—
— (SST)	NOAA/NCEP Real-Time Global Sea Surface Temperature Analysis (RTGSST)	—	—
Land-Use	GSI digital national land information (100 m mesh)		

GSI, Geographical Survey Institute; JMA, Japan Meteorological Agency; NCAR, National Center for Atmospheric Research; NCEP, National Center of Environmental Prediction; NOAA, National Ocean and Atmospheric Administration.
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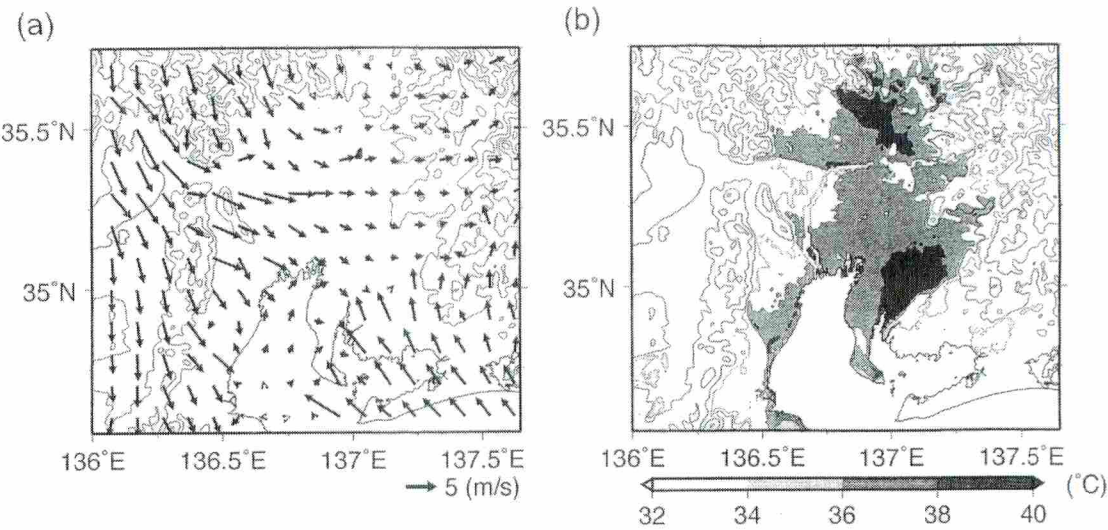
Fig. 8　(a) Wind field (vector) and (b) surface air temperature (shading) at 14:00 JST on August 18, 2010 from the WRF model control simulation (CTRL)

The solid lines indicate elevation with contour intervals of 300 m. The circle represents Tajimi Station.
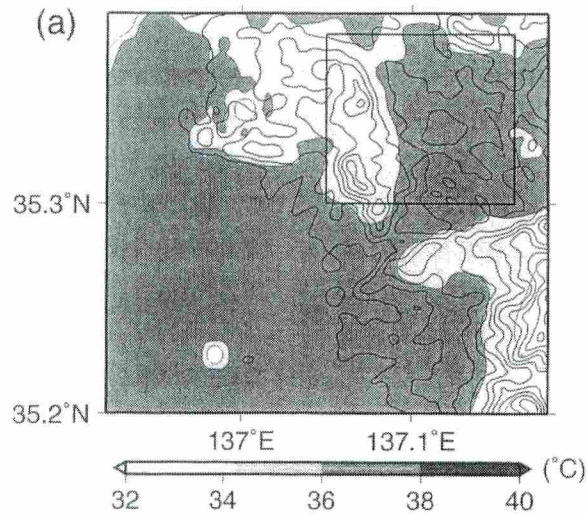

Fig. 9　Surface air temperature (shading) at 14:00 JST on August 18, 2010 in Tajimi and Kasugai from the WRF model control simulation (CTRL)

The thin solid line represents elevation with contour intervals of 50 m. The thick solid square represents the area of Tajimi.

Table 3　Physics of the WRF model used in the present numerical experiments (control simulation: CTRL)

	Physics	Reference
Microphysics	WMS3	Hong et al. (2004)
Radiation (Long-wave)	RRTMG	
Radiation (Short-wave)	RRTMG	
Boundary Layer	MYNN Level 3	Nakanishi and Nino (2004: 2009)
Surface Layer	MYNN (base on similarity theory)	—
Land-Surface (No-Urban area)	Noah LSM	Chen and Dudhia (2001)
Land-Surface (Urban area)	Single-Layer UCM	Kusaka et al. (2001)

Table 4   Specifications of the WRF model used in the sensitivity experiments with the physics parameterization scheme

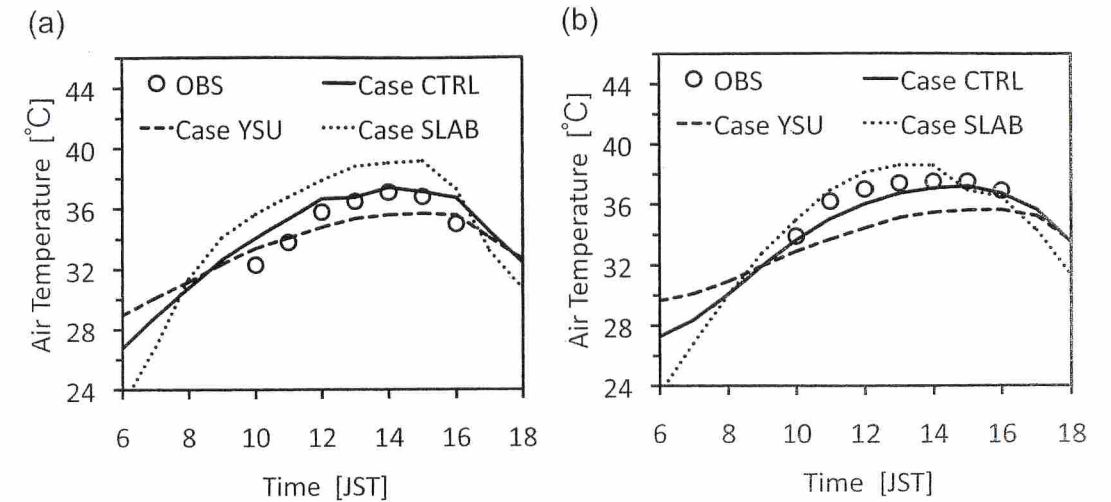| Case	Boundary layer	Land-surface	Radiation (Long-wave)	Radiation (Short-wave)
Case CTRL	MYNN 3	Noah LSM+SLUCM	RRTMG	RRTMG
Case YSU	YSU	Noah LSM+SLUCM	RRTMG	RRTMG
Case SLAB	MYNN 3	SLAB	RRTMG	RRTMG
Case DUDHIA	MYNN 3	Noah LSM+SLUCM	RRTM	Dudhia

Fig. 10   Diurnal variation in surface air temperature from 06:00 to 18:00 JST on August 18, 2010 in (a) Taihei Park in Tajimi and (b) Harumi Park in Kasugai
The circles represent observed results, the solid line CTRL results, the dashed line YSU results, and the dotted line SLAB results.

Table 5   Daytime (10:00–16:00 JST) average bias of WBGT on August 18, 2010 in Taihei Park in Tajimi and Harumi Park in Kasugai

Park	Case	WBGT [°C]	$0.7T_w$ [°C]	$0.2T_g$ [°C]	$0.1T_d$ [°C]
Taihei	Case CTRL	−0.1 (1.3)	0.1	−0.3	0.1
	Case YSU	−1.6 (2.2)	−1.0	−0.5	−0.1
	Case SLAB	6.8 (6.9)	6.5	0.1	0.2
	Case DUDHIA	−0.1 (1.3)	0.1	−0.3	0.1
	Uncertainty	8.4 (5.6)	7.5	0.6	0.3
Harumi	Case CTRL	−0.6 (0.6)	−0.1	−0.4	−0.1
	Case YSU	−2.0 (2.0)	−1.1	−0.7	−0.2
	Case SLAB	5.7 (5.8)	5.8	−0.2	0.1
	Case DUDHIA	−0.6 (0.7)	−0.1	−0.4	−0.1
	Uncertainty	7.7 (5.2)	6.9	0.5	0.1

Results of sensitivity experiments with the physics parameterization scheme in the WRF model. Figures in parentheses indicate the root mean square error (RMSE).
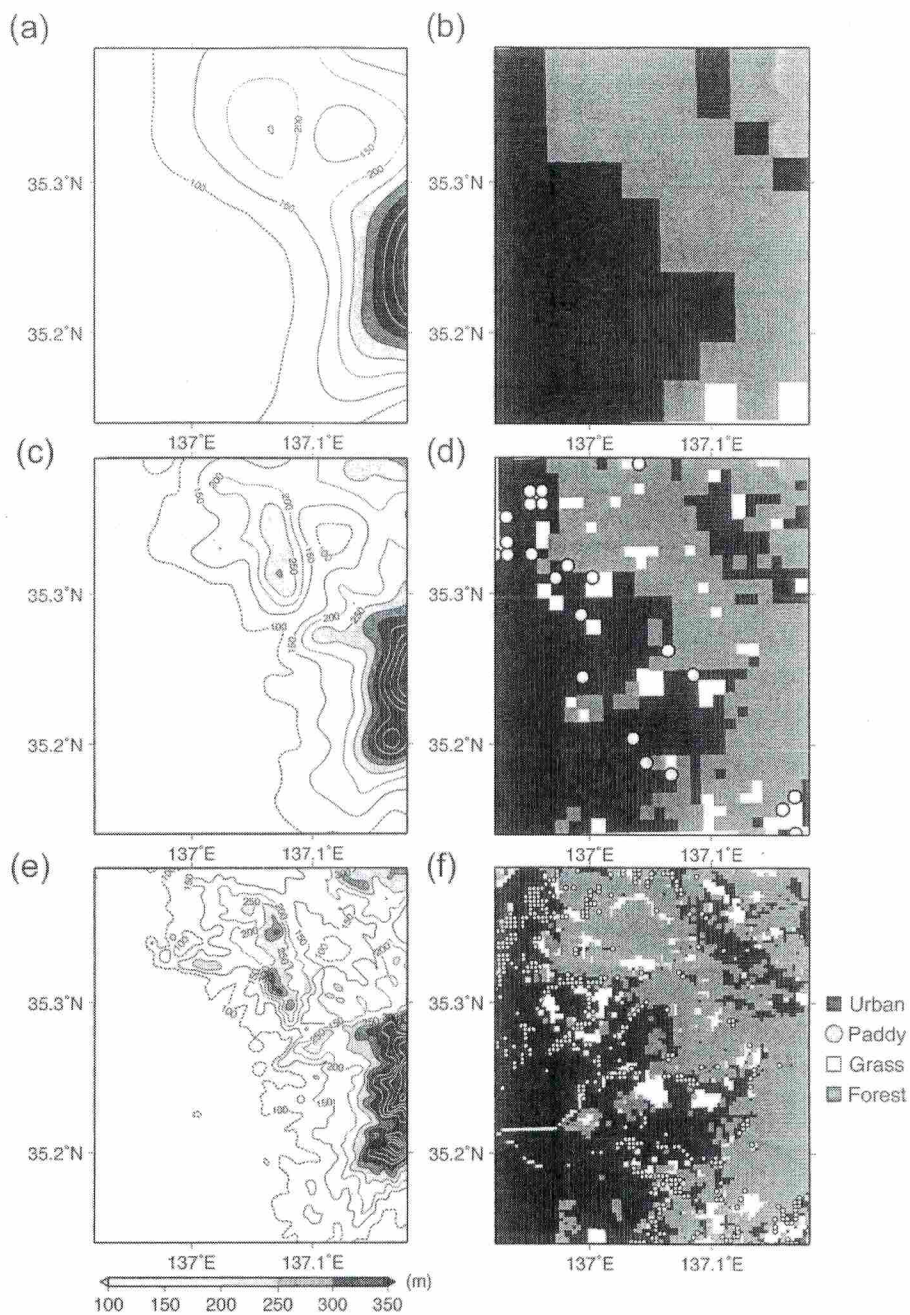
Fig. 11　Topography (left) and land-use categories (right) in the Tajimi–Kasugai–Nagoya region (a), (b) Low (2.7-km horizontal resolution), (b), (c) CTRL (0.9-km horizontal resolution), (e), (f) High (0.3-km horizontal resolution).
The solid lines in the left panels indicate elevation with contour intervals of 50 m. The dashed topographic lines (left) correspond to elevation with contour intervals of 100 m. The shading in the right panels indicates land-use categories.

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Table 6　(a) Daily maximum WBGT and (b) daytime (10:00–16:00 JST) average WBGT on August 18, 2010 in Taihei Park in Tajimi and Harumi Park in Kasugai from the WRF model control simulation (CTRL)

(a)

Park	Time [JST]	WBGT [°C]	$0.7T_w$ [°C]	$0.2T_g$ [°C]	$0.1T_d$ [°C]
Taihei	13	32.5	18.6	10.2	3.7
Harumi	14	32.5	18.6	10.2	3.7

(b)

Park	WBGT [°C]	$0.7T_w$ [°C]	$0.2T_g$ [°C]	$0.1T_d$ [°C]
Taihei	31.8	18.1	10.1	3.6
Harumi	31.8	18.3	9.9	3.6

Table 7　Daytime (10:00–16:00 JST) average bias of WBGT on August 18, 2010 in Taihei Park in Tajimi and Harumi Park in Kasugai

Park	Case	WBGT [°C]	$0.7T_w$ [°C]	$0.2T_g$ [°C]	$0.1T_d$ [°C]
Taihei	Case LOW	−0.6 (1.3)	−0.2	−0.4	0.0
	Case CTRL	−0.1 (1.3)	0.1	−0.3	0.1
	Case HIGH	−0.2 (1.2)	0.0	−0.3	0.1
	Uncertainty	0.5 (0.1)	0.2	0.1	0.1
Harumi	Case LOW	−0.8 (0.8)	−0.3	−0.4	−0.1
	Case CTRL	−0.6 (0.6)	−0.1	−0.4	−0.1
	Case HIGH	−0.5 (0.4)	−0.1	−0.4	0.0
	Uncertainty	0.3 (0.4)	0.2	0.0	0.1

Results of sensitivity experiments with horizontal resolutions of the WRF model. Figures in parentheses indicate the root mean square error (RMSE).
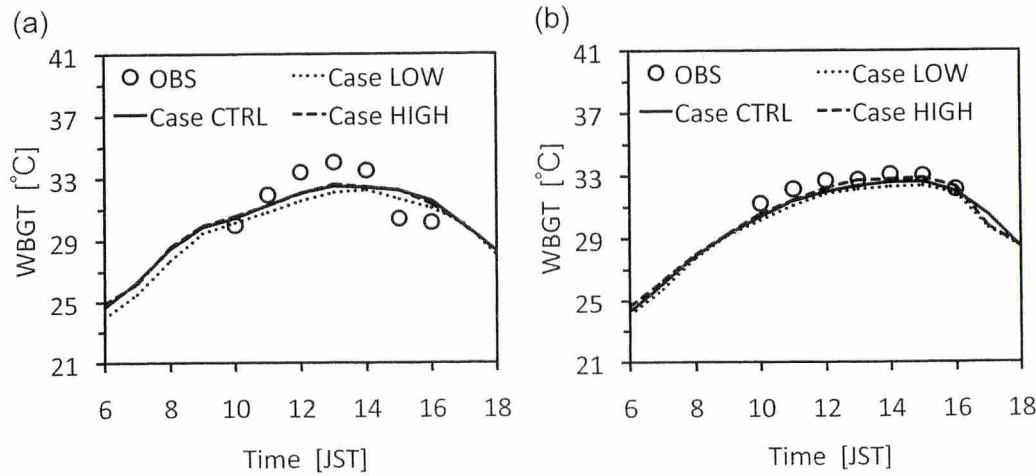

Fig. 12　Diurnal variation of WBGT from 06:00 to 18:00 JST on August 18, 2010 in (a) Taihei Park in Tajimi and (b) Harumi Park in Kasugai
The circles represent observed results, the dotted line low results, the solid line CTRL results, and the dashed line high results.
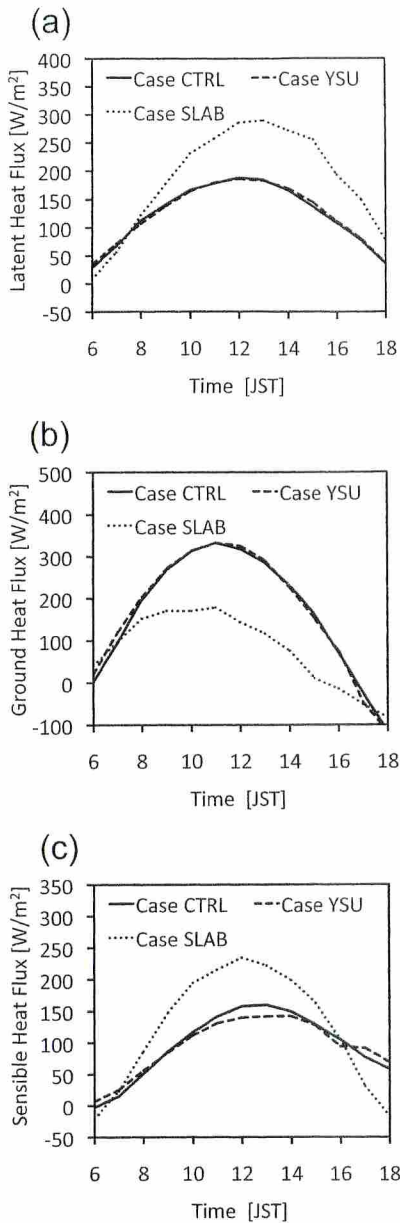
Fig. 13   Diurnal variation in (a) latent heat flux,
           (b) ground heat flux, and (c) sensible
           heat flux from 06:00 to 18:00 JST on August
           18, 2010 in Taihei Park in Tajimi
The solid line represents CTRL results, the dashed line YSU
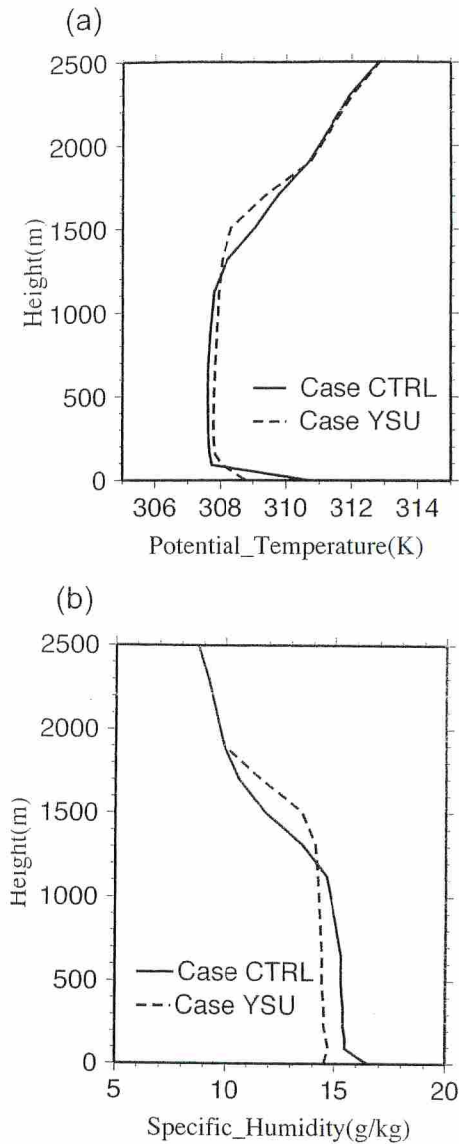results, and the dotted line SLAB results.

Fig. 14   Vertical profiles of (a) potential temperature and (b) specific humidity at 14:00 JST on August 18, 2010
           in Taihei Park in Tajimi
               The solid line indicates CTRL results, and the dashed line YSU results.