

Field Experiment on the Effects of a Nearby Asphalt Road on Temperature Measurement

T. Hamagami^{a*}, M. Kumamoto^a, T. Sakai^a, H. Kawamura^a, S. Kawano^a, T. Aoyagi^b, M. Otsuka^c,
and T. Aoshima^a

^a Meteorological Instruments Center, Japan Meteorological Agency, Tsukuba, Japan

^b Meteorological Research Institute, Tsukuba, Japan

^c Japan Meteorological Agency, Tokyo, Japan

1. Introduction

It's well-known that temperature measurements are affected by environmental conditions of meteorological observing stations. Buildings or trees around the stations may reduce air flow or project shades, thus generate measurement errors. Asphalt pavement surfaces such as roads or car parks may act as heat sources. As many observing stations in Japan are located in cities that have undergone rapid industrialization and may be under influence of urban warming (Fujibe 2010), more attention should be paid to evaluation of the surroundings of observing sites in terms of monitoring local climate. Fujibe (2009) described the possibility of detecting microscale effects related to changes in site environment on long term observed temperature with a statistical analysis using 29 years of the Automated Meteorological Data Acquisition System data in Japan. On the other hand, a field experiment at the KNMI-terrain in De Bin (the Netherlands) showed that a slight change in site exposure may bring substantial difference in the readings of thermometers (Brandsma, 2004). These studies indicated that the wind conditions around a site play a key role in deciding the magnitude of the bias in temperature measurement caused by local environmental factors. However, in real settings of a site or its long term data series, several effects are so complicatedly mixed that it is difficult to separate and quantify the contribution from each factor. It is a great interest for both observing network managers and data users to clarify to how much extent each factor can cause measurement errors in order to design optimal networks suitable for their purposes, to keep the observing stations in a good state and to estimate true values that represent local climate.

According to the siting classification of WMO (2010), the main factors which adversely affect temperature measurements are unnatural surfaces and shading. This study solely focuses on the effect of artificial surfaces, specifically an asphalt car road near a thermometer and aims to evaluate it quantitatively by a field experiment. The experiment field was selected to avoid the effects from other factors than a car road as much as possible. The thermometers were installed at different distances from the road at different heights to describe the temperature variation near the road both horizontally and vertically. The continuous observations were conducted in summer (30th June - 1st October 2010) and winter (29th November 2010 - 6th January 2011) to include various patterns of advection in the vicinity of the road.

* Correspondence to: Takashi Hamagami, Meteorological Instrument Center. E-mail: ta.hamagami@met.kishou.go.jp

2. Instrumentation and data

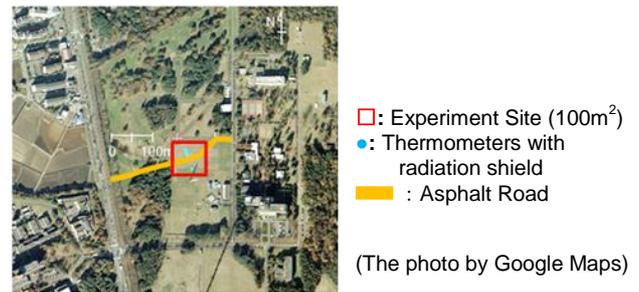


Fig.1. Location of the experiment site

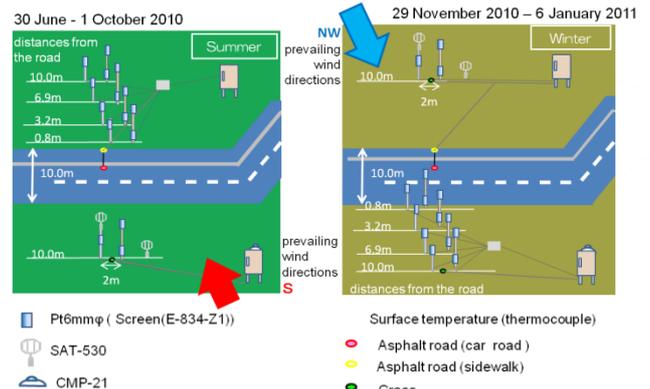


Fig.2. Layout of Instrumentation

The experiment site was set up at the Meteorological Instruments Center of Japan Meteorological Agency in Tsukuba, Japan (36 ° 3.4' N, 140 ° 7.5' E). The site is inside an area of the city where several scientific research institutes are located, well away from residences and surrounded by a vast open space covered by vegetation.

As Figure 1 shows, the nearest buildings stand a few hundred meters away. There are not any artificial heat sources or objects that project shade within 100 m² except a 10.0 m wide asphalt car road that crosses the site from east to west. The layout of the instrumentation is shown in Figure 2. The sample thermometers with radiation shields were installed on one side of the asphalt road at the four different distances of 0.8 m, 3.2 m, 6.9 m and 10.0 m from the road, making up 45%, 30%, 10% and 0% respectively of the area within a 10 m circle around each sample point occupied by the road. At each sample point, three thermometers were mounted at different heights of 0.5 m, 1.5 m and 2.5 m from the ground. The reference temperatures were measured on the opposite side of the road at a distance of 10.0 m at each of the same three levels as those of the sample temperatures. The reference side was situated mainly on the windward side considering the prevailing wind directions that are different in summer and in winter around the experiment site. The sensors of the thermometers (Pt 100Ω, 6 mm in

diameter) were calibrated several times in a measurement chamber (liquid bath type) during the experiment period to give adjustment to the observed values.

Several parameters other than temperature were also measured in the experiment. Two ultra-sonic anemometers and a pyranometer were installed to monitor the weather conditions of the site. The anemometers were mounted at the height of 0.5 m and 2.5 m near the reference point. Surface temperatures of the road and the grass field were measured at 3 cm from the ground by thermocouple thermometers. The radiation balance on the two types of surface, asphalt and grass, was measured once during each experiment period of summer and winter (on August 16 and January 6) by an albedometer. In addition, surface temperature distributions around the site most typical to each season were observed using a radiation thermometer (THERMO-TRACER TH7100) on August 16, September 3 and January 5.

The data sampling frequency for the thermometers, thermocouple thermometers and the pyranometer was 1.0 seconds, for the anemometers, every 0.25 seconds. In the data analysis, the values for the thermometers and the thermocouple thermometers were processed into moving averages for every ten seconds, for the anemometers, three seconds averages for every ten seconds. When the temperature of a thermometer at a sample point is T , and that of the thermometer at the same height at the reference point is T_0 , δT at the sample point is defined as the difference temperature,

$$\delta T = T - T_0$$

3. Results

The frequencies of wind direction around the site during the periods of summer and winter are shown in Figure 3.

Figure 4 presents the frequency distributions of all the δT s at each of the four sample points at the three different heights of 0.5 m, 1.5 m and 2.5 m during the two whole

periods of summer and winter. In summer, the patterns of the distributions for southerly winds (ESE - SSW) were similar to each other and quite a contrast to those for their opposite directions (WNW - NNE). Thus, these two different groups are composited separately and presented by different lines in each graph of Figure 4. In order to categorize them, all the distributions were examined beforehand by each of the sixteen directions, eight principal winds (N, NE, E, SE, S, SW, W, NW) and eight half winds (NNE, ENE, ESE, SSE, SSW, WSW, WNW). The cases for winter were divided in the same manner into the two groups of southerly winds (ESE - SW) and northerly winds (WNW - NE).

In summer, the peaks of the patterns for southerly (ESE - SSW) winds incline to the right from the center (0.0 °C) at a height of 0.5 m, while those for northerly (WNW - NNE) winds appear at the negative area in the graphs of Figure 4. The scale of the positive bias is from +0.2 °C to +0.4 °C from the readings in the graphs at the right edge of the peaks. The shorter the distance from the road is, the more the positive biases are seen. This trend becomes less conspicuous as the mounting height becomes higher. The same thing is true to winter, though a distribution at a height of 0.5 m has one sharp peak unlike that of summer with several peaks. The scales of biases are smaller in winter than in summer. As the windward direction of the road is southerly in summer while northerly in winter, these results indicate the direct effects of the heated air over the road that was transported by the wind.

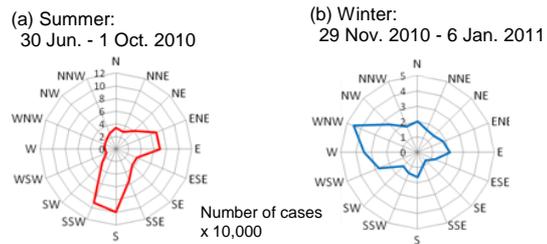
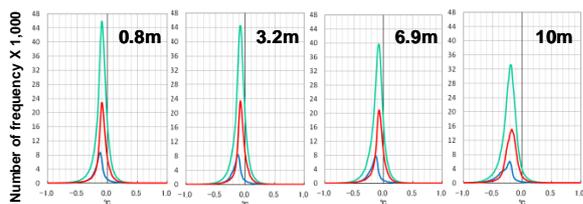


Fig. 3. Frequency of wind direction, (a) summer and (b) winter.

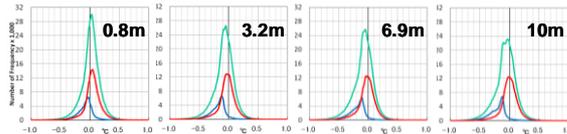
Summer: 30 Jun. - 1 Oct. 2010

(a) 2.5 m

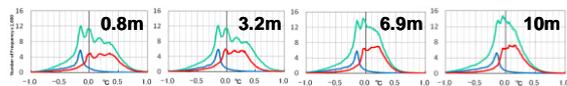
— All cases
— Southerly (ESE - SSW)
— Northerly (WNW - NNE)



(b) 1.5 m



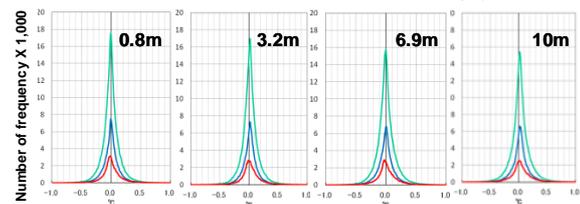
(c) 0.5 m



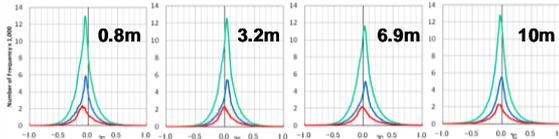
Winter: 29 Nov. 2010 - 6 Jan. 2011

(d) 2.5 m

— All cases
— Southerly (ESE - SW)
— Northerly (WNW - NE)



(e) 1.5 m



(f) 0.5 m

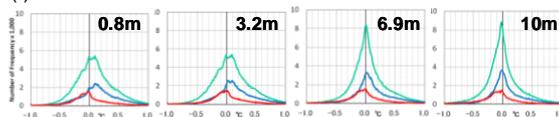


Fig. 4. Frequency distributions of δT s. (a) The numbers of frequency of δT s from 30 June to 1 October at a height of 2.5 m, (b) the same as (a) except a height of 1.5 m and (c) the same as (a) except a height of 0.5 m. (d) The numbers of frequency of δT s from 29 November to 6 January at a height of 2.5 m, (e) the same as (d) except a height of 1.5 m and (f) the same as (d) except a height of 0.5 m. Each figure from (a) to (f) consists of four histograms for the four different sample points, at distances of 0.8 m, 3.2 m, 6.9 m and 10.0 m from the road.

In Figure 5, the frequency distributions of δT s by wind speed are shown when the effects from the road are expected to be significant. The cases for these distributions were chosen when the sample points were on the leeward side and the surface temperature difference between the road and the grass field was equal to or more than a threshold value, 10.0 °C for summer and 4.0 °C for winter. More variations and positive biases are seen when the wind speed becomes lower in all the graphs. In summer, at a height of 0.5 m, the highest frequency appears at around +0.5 °C at a distance of 0.8 m, slightly shifting to the left as the thermometers are away further from the road and diminishing to +0.2 °C at a 10.0 m distance. It appears at around +0.1 °C at a height of 1.5 m, while around 0.0 °C or below at a height of 2.5 m. In winter, a wide range of variations is seen when the wind is weak as below 1.0 ms^{-1} at every sample point at every height. The highest frequency exists around from +0.5 °C to +0.3 °C at a height of 0.5 m.

The characteristics of time dependence of δT are investigated in relation to the surface temperatures and the wind speeds around the site. Figure 6 shows the diurnal change patterns of δT at each of the four sample points at the three different heights, surface temperature of the road and the grass field, and wind speed for Middle Summer (MS: July 17th - August 31st) and Middle Winter (MW: December 6th - January 6th). The observed values of each parameter were smoothed to every ten minutes values and averaged for each of the two periods. The frequencies of wind directions during these periods were almost the same as shown in Figure 3. There was not much difference in the wind directions between day and night (not shown here).

In Figure 6, the averaged δT at the nearest point (a 0.8 m distance) from the road at a 0.5 m height shows the widest range of anomalies both in MS and MW. As the distance from the road widens at the other sample points, the range of the biases becomes smaller. There are very slight variations at a height of 1.5 m and 2.5 m of all the sample points, indicating less dependence on the effects from the road than at a 0.5 m height.

In MS, surface temperature of the road goes up to 55 °C at the peak hours of 1200 - 1400 Japan Standard Time (JST) and remains high around 30 °C or more during

the night, making the difference of 8 -14 °C from that of the grass field all through the day. The wind speed is so low as 0.5 ms^{-1} during the night that creates the conditions where the road and the nearby air heated during the day act as a heat source for prolonged hours. The wind is as strong as over 1.5 ms^{-1} during 1200 - 1800 JST, so that the air exchange around the site is promoted to suppress the biases at the sample points that fluctuate due to the air convection generated by the heated road. Thus, the peak of the positive biases in δT appears early evening around 1900 JST with the scale of +0.47 °C at maximum at a 0.8 m from the road at a height of 0.5 m. On the other hand, in MW, the difference of surface temperature between the road and the grass field is larger at night than during the day. When the wind gets weaker to around 1.0 ms^{-1} at night and radiation cooling occurs, local inversion layers might be easily formed in the lower atmosphere over the grass field, while the air closed to the asphalt surface is relatively warm. That is considered to be the reason why more positive biases in δT can be seen all through the night at a height of 0.5 m as the sample points get near to the road.

Table 1. Albedos measured by albedometer

Surface	Albedo	
	Summer (16 August 2010)	Winter (6 January 2011)
Asphalt road	0.098	0.142
Grass field	0.157 - 0.188	0.206 - 0.247
Bare ground	-	0.176

The albedos of the asphalt surface and the grass field were measured by the albedometer (Table 1). The result corresponded with the well-known fact that the asphalt absorbs more short-wave radiation with lower albedos than the grass. Measurement by thermotracer confirmed that the surface temperature was uniformly distributed over each of the two kinds of surface, the asphalt and the grass without unevenness. The high surface temperature of the asphalt was around 55 °C in summer and 20 °C in winter, while that of the grass was around 40 °C in summer and 18 °C in winter according to the measurement by thermocouple thermometers.

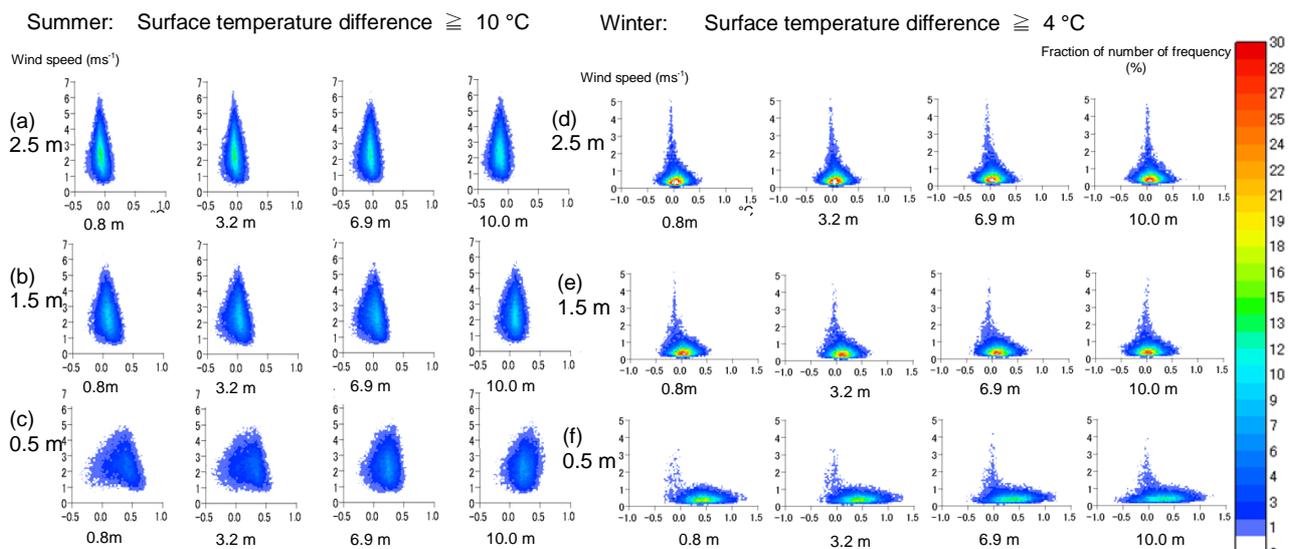


Fig. 5. Frequency distributions of δT by wind speed. Each figure from (a) to (f) presents the same position and period as described in Figure 4. The difference of surface temperature between the asphalt and the grass was equal to or more than 10 °C and 4 °C, in summer and winter respectively.

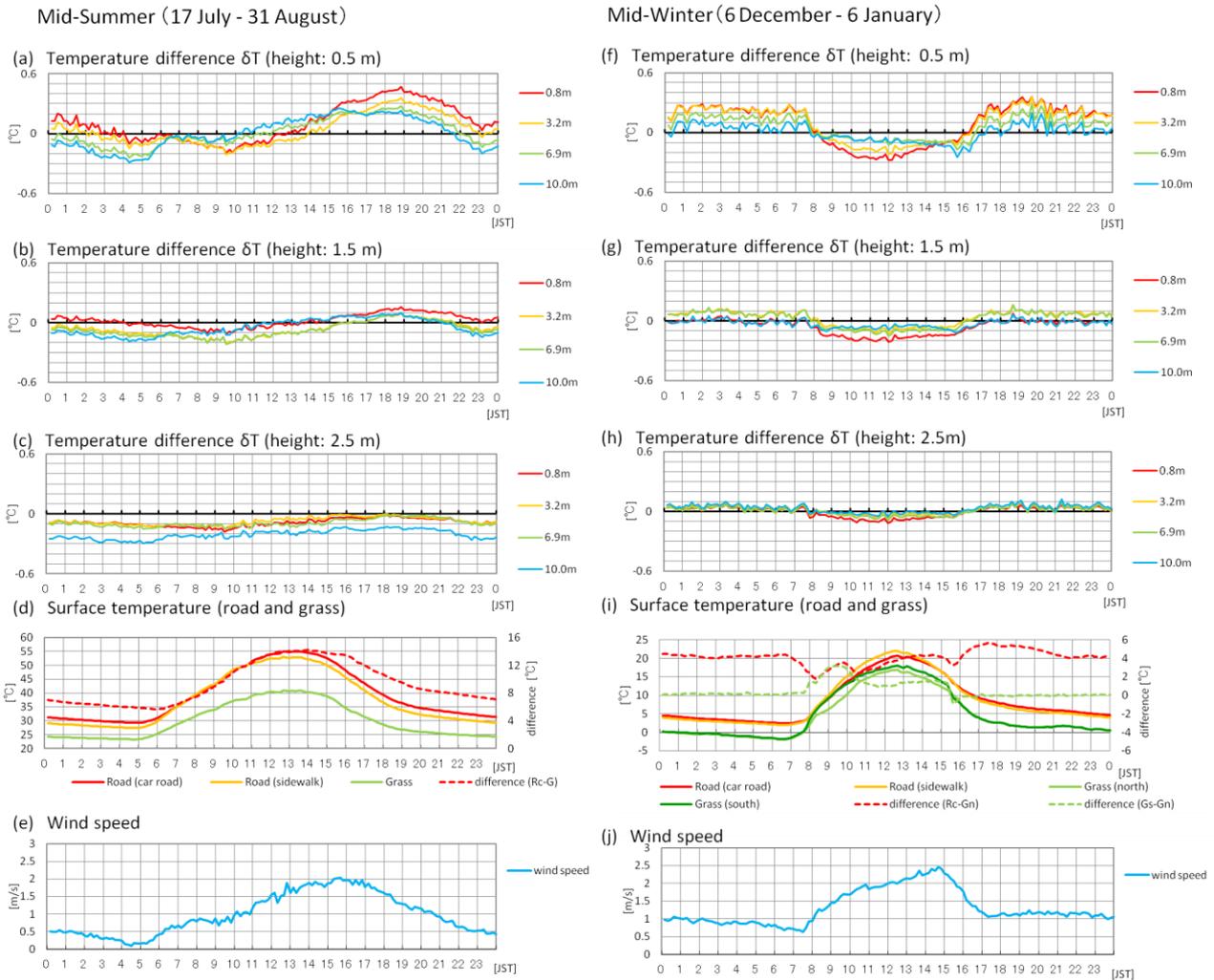


Fig. 6. Diurnal changes of δT , surface temperature and wind speed. (a) The diurnal changes of δT observed at each of the four sample points during the Mid-Summer period at a height of 0.5 m, (b) the same as (a) except a height of 1.5 m, and (c) the same as (a) except a height of 2.5 m. (d) The diurnal change of surface temperature of the asphalt road and the grass field and (e) wind speed. Each figure of from (f) to (j) presents the same parameter for Mid-Winter as from (a) to (e) for Mid-Summer.

Finally, a comparison with a 2-d model simulation was conducted in order to better understand the mechanism of the situation where the asphalt road acts as a heat source. The simulation intends to describe a real observed situation as a snapshot at one typical summer night (1920 JST, 3, September, 2010) when the effects of the asphalt road were considered to be significant. The model domain was horizontally 70 m with 1 m resolution and 20 m with 0.6 m resolution in vertical direction. The level-2 turbulent closure model of Mellor and Yamada (1974, 1982) was used. The upper boundary was set to constant wind speed of 2.0 ms^{-1} and constant temperature of $27 \text{ }^\circ\text{C}$ according to the observed values. Initial and inflow conditions of wind and temperature were estimated applying the Monin-Obukhov similarity theory up to 20 m. The road temperature was set to $37 \text{ }^\circ\text{C}$, while the surface temperature of the grass field was set to $28 \text{ }^\circ\text{C}$.

Figure 7 shows the temperature distribution after enough time integrations to establish an equilibrium state. As a result, the temperature difference (δT) is larger in simulation than in observation (Table 2). The model slightly underestimates wind speed compared to the observations. However, the computing δT s well agreed overall with the observing δT s.

Table 2. Comparison of computing δT s and wind speed with those of observation

Parameter	Simulation	Observation
δT (height : 2.5 m)	+ 0.1 $^\circ\text{C}$	- 0.1 — - 0.2 $^\circ\text{C}$
δT (1.5 m)	+ 0.2 $^\circ\text{C}$	0.0 $^\circ\text{C}$
δT (0.5 m)	+ 0.6 — + 0.3 $^\circ\text{C}$	+ 0.3 — + 0.1 $^\circ\text{C}$
Wind speed	1.7 ms^{-1} (height: 2.7 m)	2.3 ms^{-1} (height: 2.5 m)

4. Conclusion

The results showed that the bias of around + 0.2 $^\circ\text{C}$ to + 0.5 $^\circ\text{C}$ were caused by the asphalt road at the height of 0.5 m from the ground depending on the distances from the road or the wind conditions. The closer the distance from the road was, the larger the bias became. A wide range of variations was seen when the thermometers were on the leeward side of the road and the wind speed was as low as 2.0 ms^{-1} in summer or 1.0 ms^{-1} in winter. The magnitude of the positive bias got smaller at higher levels from the ground where the effects of the heated road were much reduced. On the contrary, a significant negative bias was seen at a distance of 10.0 m at a height of 2.5 m. The reason for that may be the effects from the surrounding vegetation, yet a further analysis is needed.

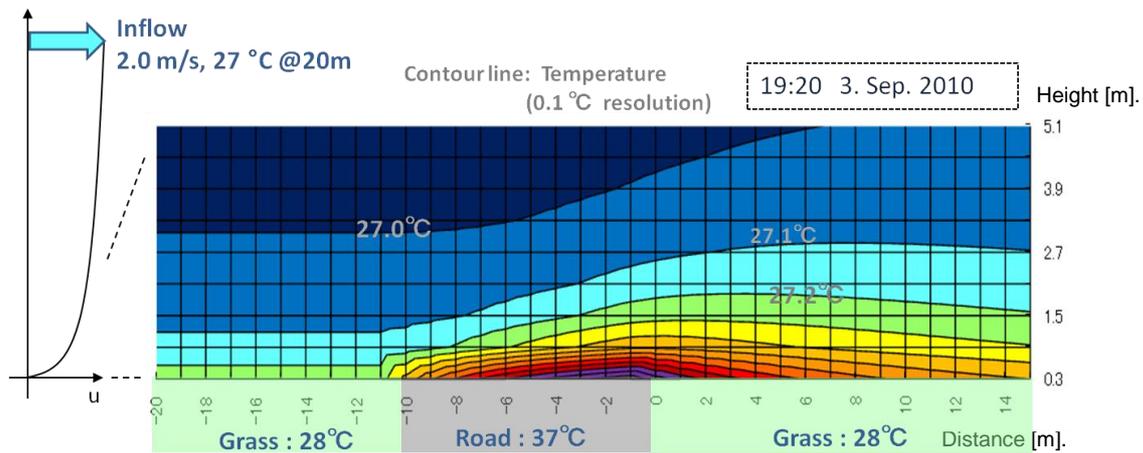


Fig. 7. Temperature distribution simulated by a 2-d model.

As to the diurnal variation, the positive peaks of temperature difference appeared at 1900 JST both in summer and in winter. When the wind was as strong as 1.5 ms^{-1} or more during the day in summer, the effect of the asphalt road as a heat source was weakened by the air exchange. In winter, the wind is weaker and the surface temperature of the asphalt is relatively higher at night than during the day, so that the positive temperature differences were seen all through the night.

The study proved that a field experiment is useful in estimating the effects of heat sources on temperature measurement at observing stations. Our way of approaching the issue was to evaluate each factor one by one to get the whole picture of the complicated system of site environment, so only the effects from an asphalt road and their relation with wind conditions were investigated as the first step. In order to further explain the mechanism where temperature measurement is affected by nearby heat sources, it is necessary to consider other factors such as terrain roughness, heat balance, soil moisture and vapor from the vegetation in the neighborhood.

More knowledge about the method of evaluating the environmental conditions of observing stations is expected from this kind of field experiment as well as computer simulations in the future.

Acknowledgments

This work was partly supported by Grant-in-Aid for Scientific Research (No. 22340141) of Japan Society for the Promotion of Science.

References

- Brandsma, T., 2004: Parallel air temperature measurements at the KNMI-terrain in De Bilt (the Netherlands) May 2003 – April 2005, Interim report. KNMI-publicatie 207 HISKLM 7, 1-29.
- Fujibe, F., 2009: Relation between long-term temperature and wind speed trends at surface observation stations in Japan. *SOLA*, 2009, Vol. 5, 081-084.
- Fujibe, F., 2010: Urban warming in Japanese cities and its relation to climate change monitoring. *International Journal of Climatology* **31**: 162-173.
- Mellor, G. L. and T. Yamada, 1974: A Hierarchy of Turbulence Closure Models for Planetary Boundary Layers, *J. Atmos. Sci.*, **31**, 1791–1806.

Mellor, G. L. and T. Yamada, 1982: Development of a Turbulence Closure Model for Geophysical Fluid Problems, *Rev. Geophys.* **20**, 851–875.

WMO, 2010: Siting classifications for surface observing stations on land. Annex IV, Commission for Instruments and Methods of Observation Fifteenth session Abridged final report with resolutions and recommendations. WMO-No. 1064.